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THESIS

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CAPT USA

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AFIT/GNE/PH/82M-7

STRATEGIC TARGETING
OF LIGHT WATER REACTORS

THESIS

Presented to the Faculty of the School of Engineering
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in Partial Fulfillment of the
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Master of Science

by
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Graduate Nuclear Engineering

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Preface

This thesis deals with the strategic targeting of light water reactors for the purpose of enhancing radioactive fallout. Previous reports have presented nuclear reactors as both desirable and undesirable targets. I present the factor by which fallout coverage is increased in targeting a nuclear reactor. This factor is a function of weapon CEP. Having presented the results, I left it up to the reader to decide whether nuclear reactors are attractive strategic targets for enhancing fallout.

I wish to thank my thesis advisor, Dr. Charles J. Bridgman, for his time and many helpful suggestions. I would also like to thank my wife for her understanding, patience and encouragement.

This thesis was typed by Sharon A. Gabriel.

Gerald R. Domaszek

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Abstract

The value of light water reactors as strategic nuclear targets for enhancing fallout is evaluated in this report. The evaluation is made by determining the ratio of the probability weighted fallout coverage from one or more weapons which involve the reactor core, to the fallout coverage from a single weapon weighted by the number of weapons targeted. This ratio is the factor by which targeting reactors will enhance the area of fallout coverage.

Targeting reactors with a single weapon will always enhance fallout coverage. However, the probabilistic amount of coverage increase is dependent on weapon CEP. Area coverage of a particular dose during the first week is increased by less than 5 percent for CEPs greater than 350 , 400, and 500 meters corresponding to yields of 100, 500, and 1000 kilotons, respectively. During the first year, the area is increased by less than 5 percent for CEPs greater than 900, 1100, and 1400 meters corresponding to yields of 100, 500, and 1000 kilotons, respectively.

Finally, multiple weapon targeting of nuclear reactors is counterproductive in that it decreases the factor by which targeting reactors increases fallout area coverage.

STRATEGIC TARGETING
OF LIGHT WATER REACTORS

I. Introduction

Various studies have been conducted on the value of nuclear reactors as strategic nuclear targets. Some conclude that lofting the core of the reactor will greatly enhance radioactive fallout and deny huge portions of land from habitation and cultivation for long periods of time (Ref 46:12), while others conclude that the augmented fallout would not be intense enough to deny the use of the land under emergency radiation exposure standards (Ref 337:4).

The problem investigated in this study is whether nuclear reactors are attractive strategic targets for enhancing radioactive fallout. The study is limited to light water reactors which are the most common type of nuclear reactors operating in the United States.

The study consists of determining the accuracy within which the weapon must land to loft the core of the reactor with the fallout cloud of the weapon and the accuracy required to cause a core meltdown. The AFIT fallout prediction model is modified to calculate the area covered by fallout from a weapon and reactor core. Finally, a means of evaluating the effectiveness of targeting a nuclear reactor for enhancing fallout is developed.

The nuclear weapons discussed in this study are assumed to be thermonuclear with 50 percent fission and used in the surface-burst mode. The reactors are assumed to be typical 3300 megawatt thermal reactors which have operated on the average at 67 percent of capacity. It is also assumed that the reactor is refueled annually by replacing one-third of the core, and that the reactor is attacked the day before it was due to be refueled.

The first step will be to calculate the probability that the core of the reactor will be vaporized and lofted, melted, or survive the nuclear detonation. Next, the AFIT fallout prediction model is modified to account for the radioactivity of the reactor core. The ratio of fallout coverage from one or more weapons involving a reactor core to the fallout coverage from weapons not involving a reactor is determined. This ratio is a function of CEP and is also the factor by which fallout coverage is enhanced in targeting nuclear reactors.

The meltdown of a reactor core is briefly examined as a method of enhancing fallout, but no evaluation similar to that conducted in the case of core lofting is undertaken.

II. Probability of Damage

One of three possible outcomes will occur when a strategic nuclear weapon is launched against a nuclear reactor. First, the reactor could be destroyed and the core vaporized and lofted with the radioactive cloud from the weapon. Second, the reactor could be destroyed or damaged and the core of the reactor eventually melted. Finally, the reactor could survive the nuclear detonation and continue to operate, or at least safely shut itself down and avoid a meltdown. The actual outcome is dependent upon the yield of the weapon and its proximity to the reactor.

The ranges within which the nuclear detonation must occur for each of the outcomes may be represented as concentric circles about the reactor as shown in Figure 1.

If the weapon lands in the inner circle, the core is vaporized and carried off in the fallout cloud. The radius of the circle corresponds to the range of the 200 psi-sec impulse (R_{200}) of the weapon. The 200 psi-sec impulse is the impulse required to rupture the pressure vessel (Ref 3:792). If the reactor vessel is ruptured, the core may be crushed and part or all of the core drawn into the fireball and vaporized. To simplify the problem, it is assumed that if the reactor vessel is ruptured, the entire core is drawn into the fireball and vaporized.

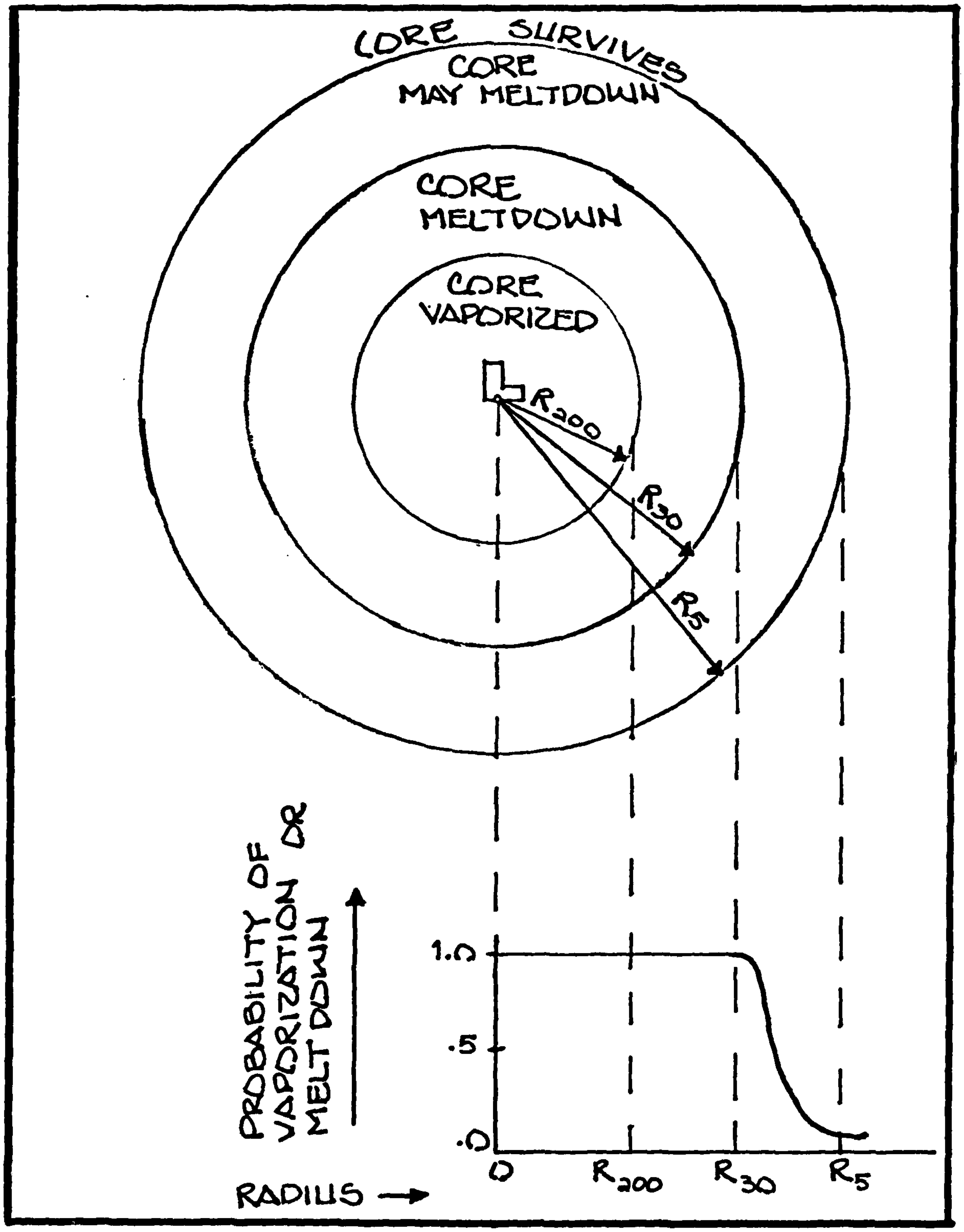

Figure 1. Probability of Damage Versus the Distance the Weapon Lands Away from the Reactor

In the next annular region, the core is not vaporized but it does definitely melt down. The region is bounded by the range corresponding to 30 psi peak overpressure of the weapon. The limit is based on the strength of reinforced-concrete structures (Refs 13:237-241; 14:159-161).

In the third annular region, the core may melt down. The region is bounded by the range corresponding to 5 psi peak overpressure of the weapon. This limit is based on the designed strength of the containment wall (Ref 3:787). The probability of a core meltdown between the 30 psi range (R_{30}) and the 5 psi range (R_5) is assumed to be a cumulative log-normal function. This assumption is consistent with the probability of damage for various similar structures. If the R_{30} and R_5 ranges are taken to represent the 98 percent and 2 percent probabilities of meltdown, respectively, then

$$P_d(R) = \int_0^R \frac{1}{\sqrt{2\pi}\ \beta r} e^{-\frac{1}{2}\left(\frac{\ell n\ r - \alpha}{\beta}\right)^2} dr \qquad (1)$$

where

$$\alpha = \tfrac{1}{2}\ \ell n(R_{30}R_5) \qquad (2)$$

and

$$\beta = \frac{1}{4.108}\ \ell n\left(\frac{R_{30}}{R_5}\right) \qquad (3)$$

describes the probability of either vaporization or meltdown over ranges from zero to infinity. For ranges less than R_{200}, Eq (1) gives the probability of vaporization, while for ranges greater than R_{200}, it gives the probability of meltdown.

The values of R_{200}, R_{30}, and R_5 are weapon yield dependent and may be determined from various graphs in References 8, 14, and 20. The values of R_{200}, R_{30}, and R_5 for yields of 100, 500, and 1000 kilotons are given in Table I.

TABLE I

Radii of Core Vaporization, Meltdown, and Survival

Yield (Kt)	R_{200} (m)	R_{30} (m)	R_5 (m)
100	57	841	2056
500	132	1438	3515
1000	231	1812	4429

The probability of whether the core is vaporized, melts down, or survives the explosion is determined by integrating, over all area, the probability the weapon hits a unit area times the probability it will cause damage. Since the probabilities are functions of radius from the target and

symmetric about the target, the probability of a particular outcome can be expressed as

$$P_d = \int_0^\infty P_h(r) P_d(r)\ 2\pi r dr \tag{4}$$

where $P_h(r)$ is the probability of the weapon landing at a radius r away from the target and $P_d(r)$ is the probability of damage at a radius r as given by Eq (1). The probability of hit function is a gaussian function of the form

$$P_h(r) = \frac{1}{2\pi\sigma^2}\ e^{-\frac{1}{2}\left(\frac{r}{\sigma}\right)^2} \tag{5}$$

where r is the radius from the target and σ is the standard deviation of the impact point distribution. The standard deviation can be expressed as follows:

$$\sigma = \left(\frac{CEP^2}{2\ln 2}\right)^{\frac{1}{2}} \tag{6}$$

where CEP is the radius of the circle of equal probability (Ref 1:18). The circle of equal probability of a weapon is a circle around a target within which 50 percent of the weapons will impact.

Since the consequences of vaporization and meltdown are different, the probability of vaporization is

$$P_v = \int_0^{R_{200}} \frac{1}{2\pi\sigma^2} e^{-\frac{1}{2}\left(\frac{r}{\sigma}\right)^2} 2\pi r dr \qquad (7)$$

where the probability of damage $P_d(r)$ is one for r less than or equal to R_{200} .

While the probability of a meltdown is

$$P_m = \int_{R_{200}}^{\infty} P_d(r) \frac{1}{2\pi\sigma^2} e^{-\frac{1}{2}\left(\frac{r}{\sigma}\right)^2} 2\pi r dr \qquad (8)$$

where $P_d(r)$ is given by Eq (1).

The probability of survival is simply expressed as

$$P_s = 1.0 - (P_v + P_m) \qquad (9)$$

where P_v and P_m are given by Eqs (7) and (8), respectively.

PRBHIT is a computer program which uses the above equations to determine the probability that the core is vaporized, melts down, or survives the targeting of a single weapon. The program is listed in Appendix A. A list of the probabilities for 100, 500, and 1000 kilotons yields for various CEPs ranging from 10 to 2500 meters is provided in Appendix B.

III. Modeling Fallout Footprints from the Lofted Core

As discussed in the previous chapter, there are three possible outcomes of an attac'- on a nuclear reactor, the first one being that of vaporizing and lofting the radioactive core with the radioactive cloud of the weapon. As part of the fallout cloud, the radioactivity of the core will return to the earth in the same manner as the weapon fallout. Several models are available for predicting the fallout footprint from the weapon cloud.

The WSEG-10 model is the standard model used to predict fallout radiation doses and dose rates. The AFIT model is a smearing code like the WSEG-10 model with a new g(t) function which incorporates particle size-activity, settling rates, and accounts for fractionation. The AFIT model provides results which are in much greater agreement with the benchmark Defense Land Fallout Information Code (DELFIC) (Ref 2:4). For the above reason, the AFIT code is used to predict the fallout from the weapons, and is modified to predict the fallout from a lofted reactor core.

To compute the fallout footprint from the weapon and reactor core, the gamma dose rate and dose from the reactor must be calculated. The beta activity from the reactor is not considered as in the case of weapon fallout because of its short range. The Way-Wigner relation for the activity

is

$$A(t) = A_1 t^{-1.2} \tag{10}$$

where $A(t)$ is the activity at time t and A_1 is the activity at one hour after fission takes place. The total activity from a weapon at time t after the explosion can be calculated knowing that the activity at 1 hour after the detonation is 530×10^6 curies per kiloton of fission yield (Ref 14:453).

For a weapon, the calculation is direct and simple using Eq (10) because all fissions occur almost simultaneously. In a reactor, the fissions occur continuously at varying rates over the entire period the reactor is operated prior to the core being disrupted. To obtain the total activity from the core, Eq (14) must be integrated over the operating time of the reactor prior to the core being disrupted.

In a reactor, 3.1×10^{10} fissions per sec or 1.116×10^{14} fissions per hour are required to produce a watt of thermal energy (Ref 16:89). In a weapon, there are 1.45×10^{23} fissions per kiloton of yield (Ref 14:13). To determine the average number of "gamma curies" per fission at 1 hour after fission, we divide the number of gamma curies per kiloton of fission by the number of fissions per kiloton. Thus,

$$\frac{530 \times 10^{6}\ \mathrm{Ci/KT}}{1.45 \times 10^{23}\ \mathrm{f/KT}} = 3.655 \times 10^{-15}\ \mathrm{Ci/f}$$

is the average number of gamma curies per fission at one hour. The total gamma activity from the core can then be defined as

$$A(t) = (3.655\mathrm{x}10^{-15}\ \mathrm{Ci/f})(1.116\mathrm{x}10^{14}\ \mathrm{f/Hr})P \int_{-t_0}^{0} (t-T)^{-1.2}\, dT(\mathrm{Hr}) \tag{11}$$

or

$$A(t) = .408P \int_{-t_0}^{0} (t-T)^{-1.2}\, dT\ \mathrm{Ci} \tag{12}$$

where P is the average operating power of the reactor core in thermal watts, t_0 is the elapsed time since reactor startup in hours, t is the time after core disruption in hours, and time is considered 0 when the core is disrupted (Figure 2). Integration of Eq (12) gives

$$A(t) = 2.04P\,[t^{-.2} - (t+t_0)^{-.2}]\ \mathrm{Ci} \tag{13}$$

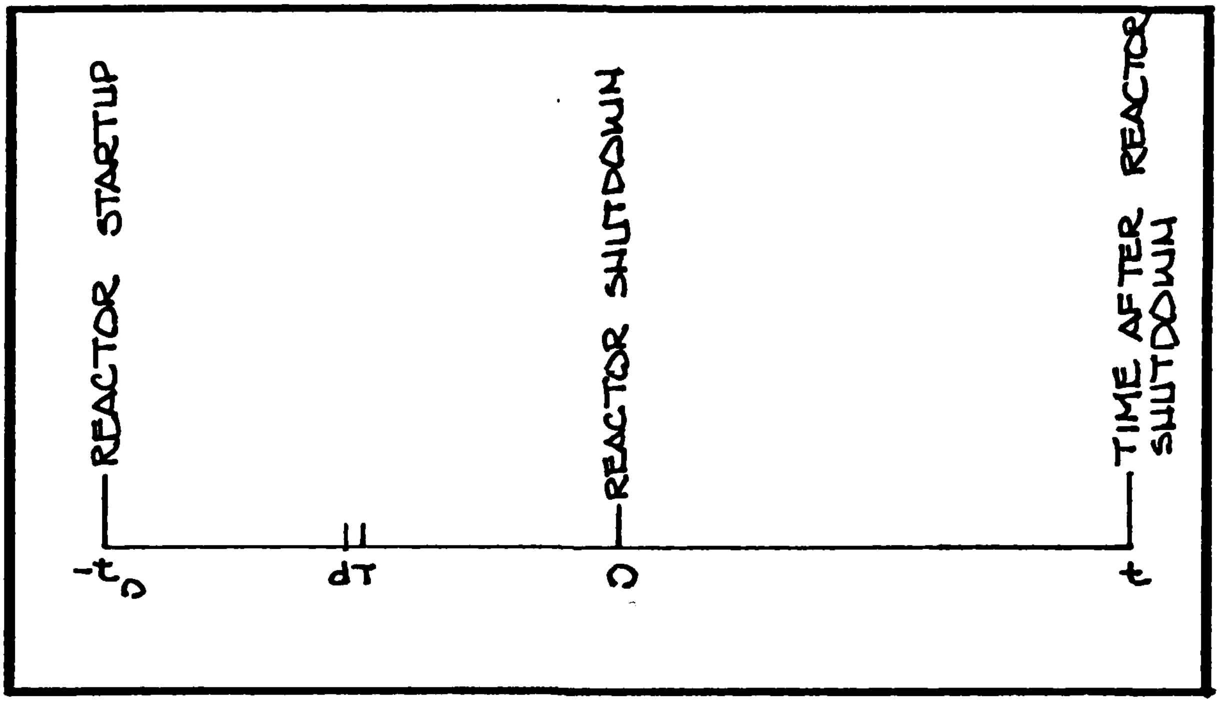

Figure 2. Calculation of Fission Product Activity

In a typical light water reactor, one-third of the fuel is changed every year (Ref 19:219). To account for the changing fuel, Eq (13) becomes

$$A(t) = .68P\,[3t^{-.2} - (t+t_1)^{-.2} - (t+t_2)^{-.2} - (t+t_3)^{-.2}]\ \text{Ci} \tag{14}$$

where t_1 , t_2 , and t_3 are the times in hours that each third of the core has been in use in the reactor when the core is lofted. Taking the weapon source normalization constant and dividing by the gamma activity per kiloton

gives a factor for converting reactor core activity to a normalized dose rate.

$$\frac{2350 \ \frac{\text{rem}}{\text{hr}} \ \frac{\text{mi}^2}{\text{KT}}}{530 \times 10^6 \ \text{Ci/KT}} = 4.434 \times 10^{-6} \ \frac{\text{rem}}{\text{hr}} \ \frac{\text{mi}^2}{\text{Ci}}$$

Multiplying Eq (14) by the above constant and changing P from watts to megawatts, the normalized dose rate from the core of the reactor is expressed as

$$\text{Dose Rate} = 3.02P \, [3t^{-.2} - (t+t_1)^{-.2} - (t+t_2)^{-.2} - (t+t_3)^{-.2}] \ \frac{\text{rem mi}^2}{\text{hr}} \quad (15)$$

where the value of 3.02 times P is here defined as the reactor normalization constant.

The normalized reactor dose is obtained by integrating Eq (15) over the time of exposure.

$$\text{Dose} = 3.02P \int [3t^{-.2} - (t+t_1)^{-.2} - (t+t_2)^{-.2} - (t+t_3)^{-.2}] \, dt \ \ \text{rem mi}^2 \quad (16)$$

The AFIT model, as well as the WSEG-10 model, is incorporated in a program called SMEAR. Program SMEAR is a FORTRAN IV program. The program has been converted to

FORTRAN V and Eqs (15) and (16) have been added into the AFIT model to account for the additional radioactive fall-out from the core of the reactor. The day before refueling the reactor was to take place was selected as the time of the attack on the reactor. This will give the worst possible case for fallout from the reactor. The times t_1 , t_2 , and t_3 in Eqs (15) and (16) will be 26256, 17496, and 8736 hours, respectively. A listing of the modified code called SMEAR1 is provided in Appendix C.

Graphs of various fallout footprints from a 1 megaton yield are illustrated in Figures 3 through 6. In the figures, the inner or smaller footprint is from a weapon alone, while the outer or larger footprint is from a weapon and reactor core.

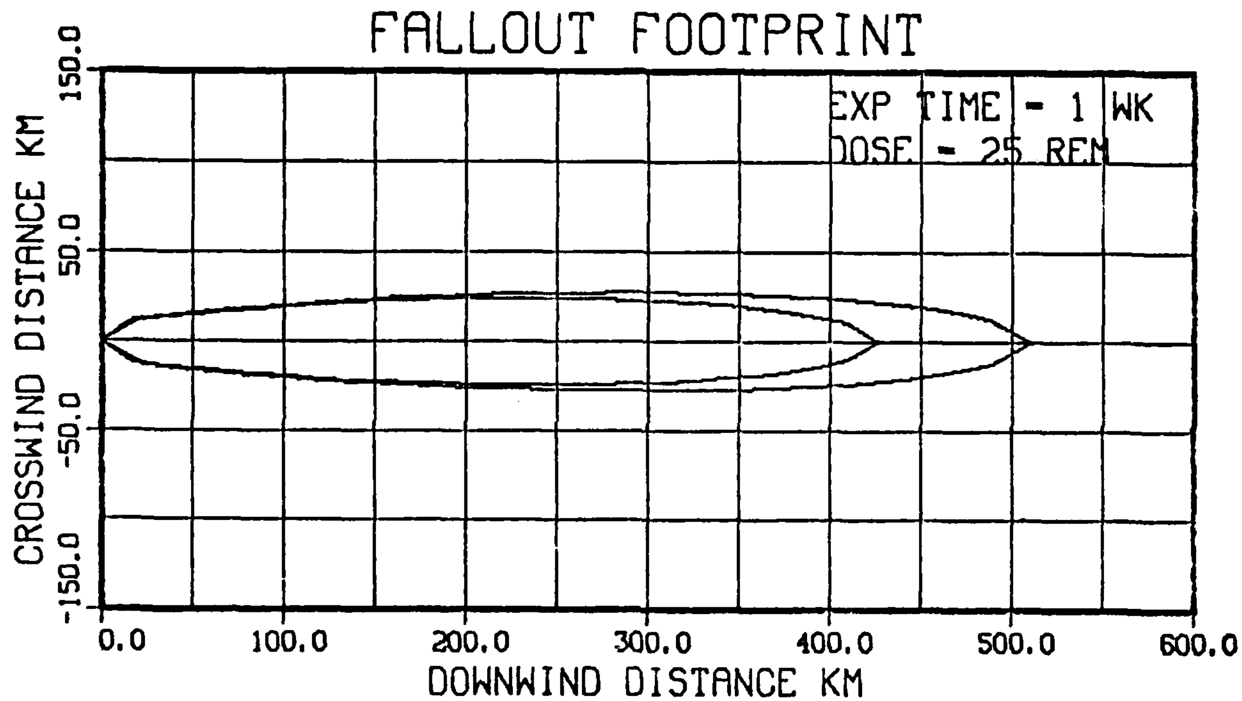

Figure 3. Fallout Footprint from a 1 Megaton Weapon

(The inner footprint is from the weapon alone, and the outer footprint is from a weapon which vaporized the reactor core.)

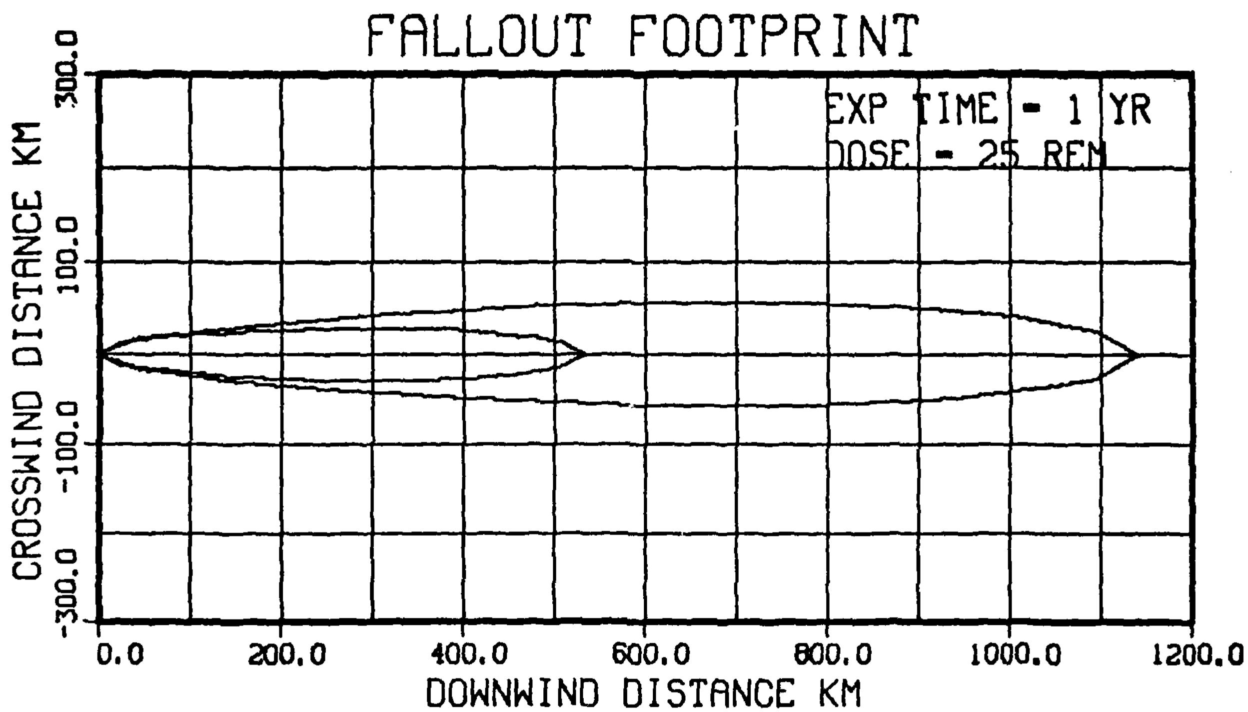

Figure 4. Fallout Footprint from a 1 Megaton Weapon

(The inner footprint is from the weapon alone, and the outer footprint is from a weapon which vaporized the reactor core.)

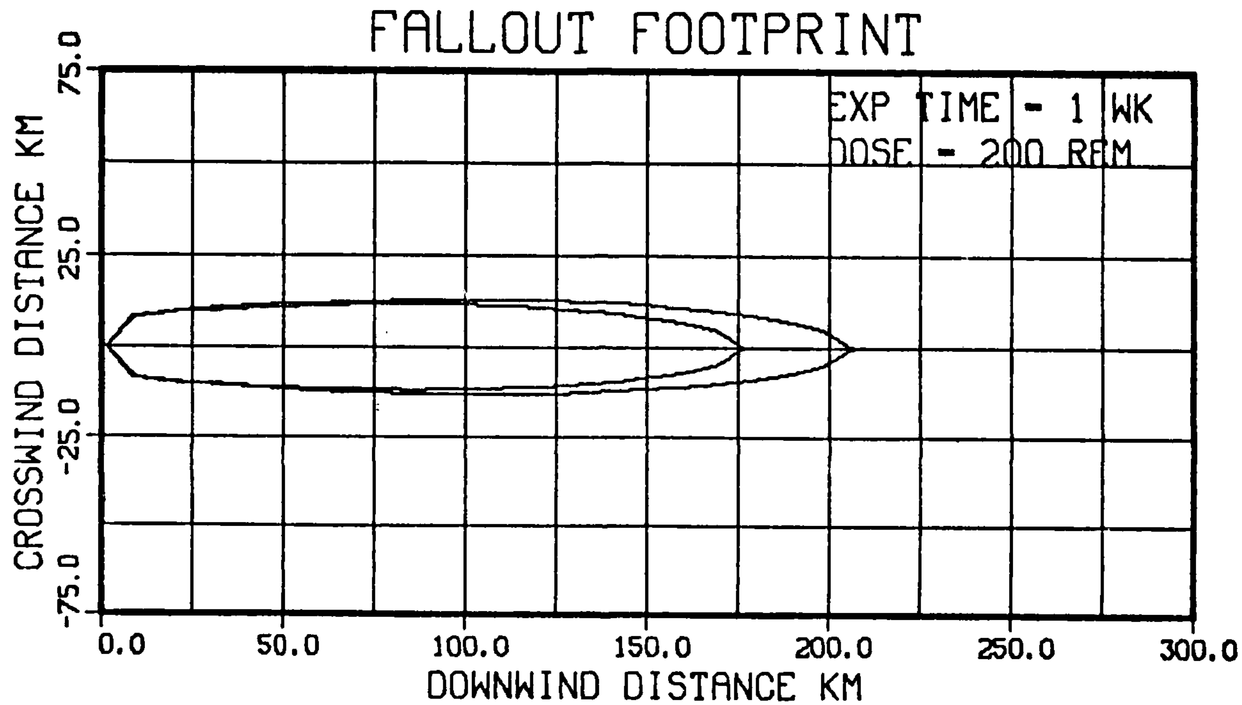

Figure 5. Fallout Footprint from a 1 Megaton Weapon

(The inner footprint is from the weapon alone, and the outer footprint is from a weapon which vaporized the reactor core.)

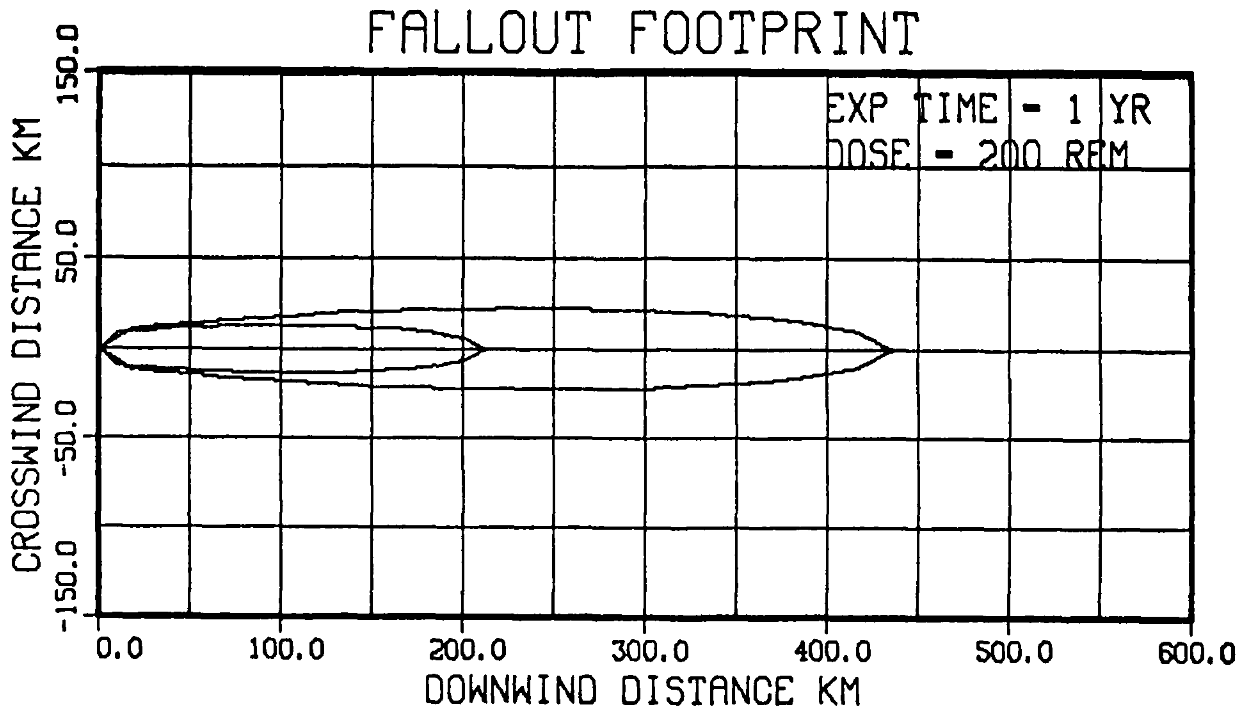

Figure 6. Fallout Footprint from a 1 Megaton Weapon

(The inner footprint is from the weapon alone, and the outer footprint is from a weapon which vaporized the reactor core.)

IV. Calculation of Fallout Coverage Enhancement

Because of aiming inaccuracies, not every weapon targeted at a nuclear reactor will detonate with the radius necessary to vaporize and loft the reactor core. There is only a probability that the core will be vaporized, and this probability is dependent on the CEP of the weapon. Thus, the additional fallout coverage from the core of the reactor must be weighted by the probability of reactor involvement.

The method used here to evaluate the effectiveness of increasing fallout coverage by targeting a nuclear reactor was to compute the ratio of fallout coverage of one or more nuclear detonations involving a reactor core to the fallout coverage of one or more weapons not involving a reactor core (Figure 7).

The doses selected for the evaluation are 25 and 200 rem. These two doses were selected because 25 rem is the emergency dose limit an individual may receive (Ref 10:53) and 200 rem is the dose where deaths begin to occur (Ref 14: 581).

The evaluation was made for both early and late times, using one week after detonation for early time and one year for late time. The two times were selected because of the difference in decay rates of weapon fallout and reactor

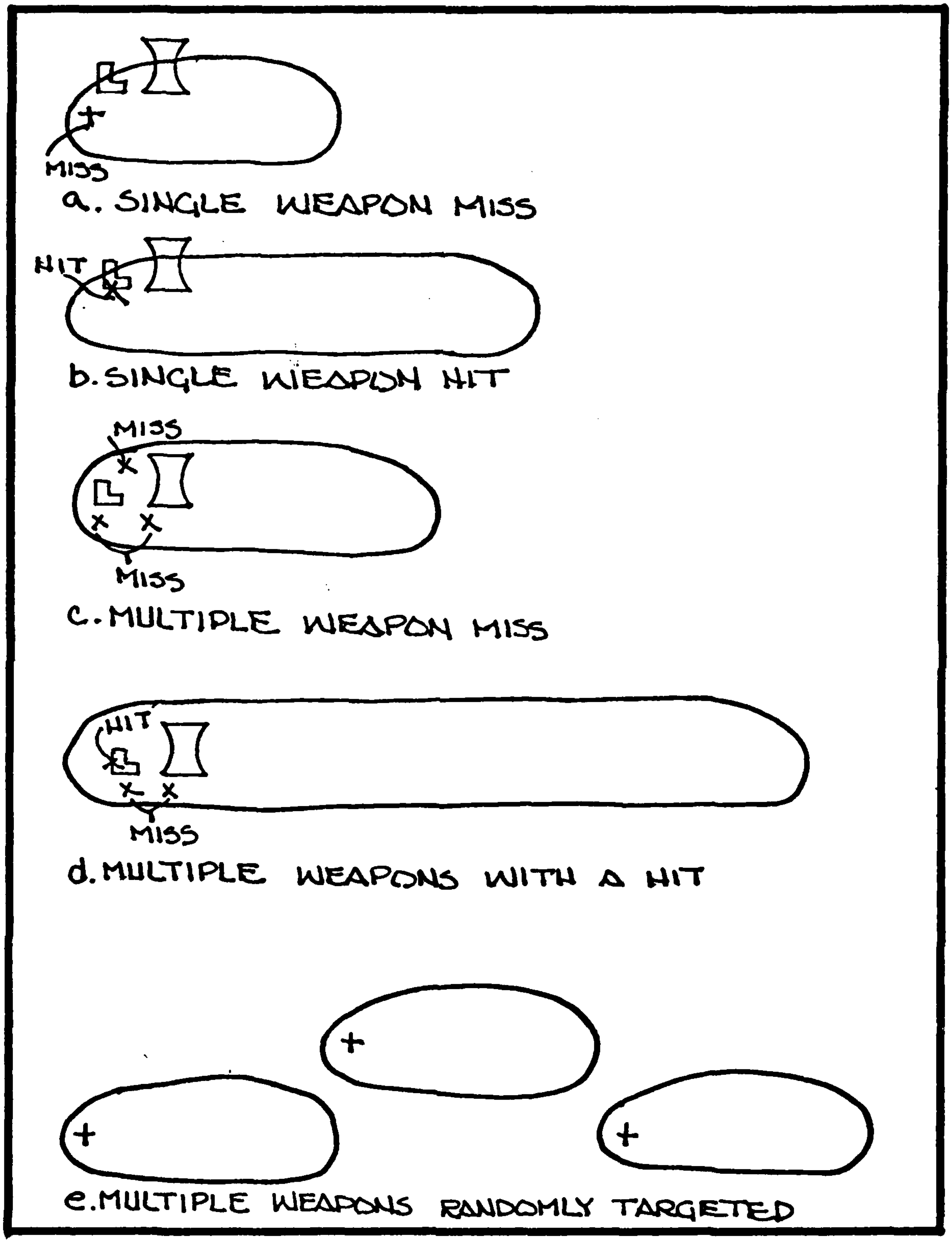

Figure 7. Fallout Footprints With and Without a Reactor

fallout. The weapon fallout decays with time as $t^{-1.2}$ while the reactor fallout decays as $t^{-.2}$ (Figure 8). Thus, at early times, most of the dose comes from the weapons, but at late times when the activity from the weapon fallout has significantly decreased, most of the dose comes from reactor fallout.

For this study, fractionation was treated by assigning .68 as the fraction of activity volume distributed in the fallout particles with a median particle radius of .204 microns and a slope of $\ell n(4)$ for the log-normal number distribution of particles with respect to radius. All of these are DELFIC standards. In addition, the following assumptions were made: (1) the weapons used were 50 percent fission, (2) the average winds aloft were 30 miles per hour, (3) the wind shear was 1.15 per hour, (4) the average operating capacity of the reactor over the life of the core was .67, and (5) the size of the reactor was 3300 megawatts thermal.

The SMEAR1 program was used to determine the footprints from one or more weapons both with and without the reactor core. The areas of the footprints are used to determine the ratio of effectiveness in targeting nuclear reactors.

The numerator of the ratio is the probability weighted down wind area enclosed within some selected contour from one or more weapons which involve the reactor core. The denominator is the downwind area enclosed within some

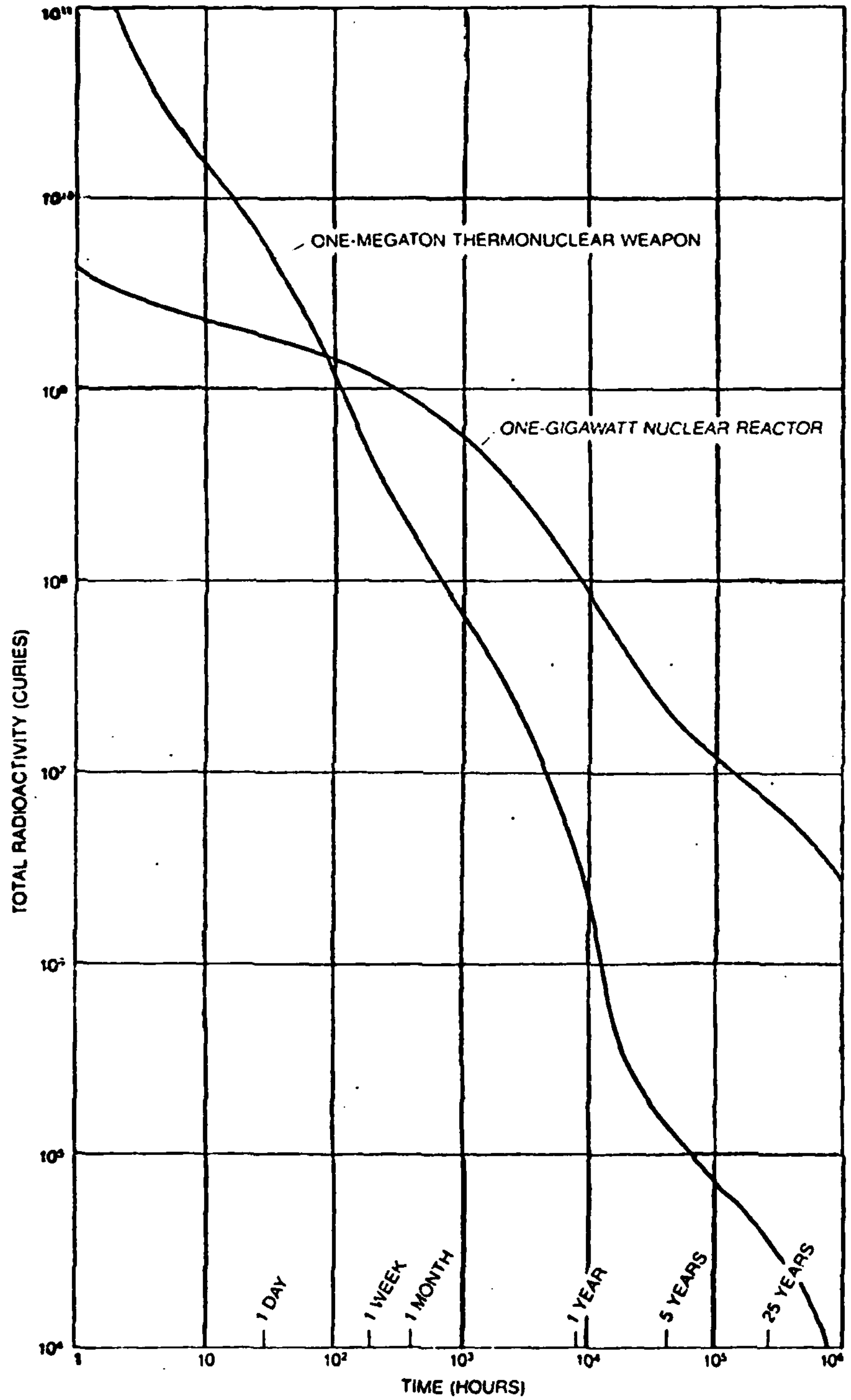

Figure 8. Decay of Radioactivity from a Weapon and Reactor (Ref 12:46).

selected contour from a single weapon not involving a reactor times the number of weapons targeted. The ratio is given by

$$R = \frac{A_w + (A_{wr} - A_w)P_v}{A_{sw}\ N} \tag{17}$$

where A_w is the area of the footprint if the weapon or weapons fail to vaporize the core (Figure 7, a and c), A_{wr} is the area of the footprint when the reactor core is vaporized (Figure 7, b and d), P_v is the probability of the additional fallout from the reactor core and is given by Eq (7), and A_{ws} is the area of fallout coverage from a single weapon without involving a reactor and N is the number of weapons targeted.

This ratio is also the factor by which fallout area coverage is increased when targeting nuclear reactors. The factor by which fallout coverage is enhanced is a function of CEP and the number of weapons targeted, as can be seen in Figures 9 through 20. A ratio of greater than 1 means it is advantageous to target the reactor, while a ratio of less than 1 means it is not advantageous to target a reactor.

For a single weapon, the ratio is always greater than 1, meaning that it is an advantage to target the reactor with at least one weapon. However, the ratio decreases quickly with increasing CEP. The actual area coverage of a particular dose during the first week is increased by

less than 5 percent for CEPs greater than 350 , 400, and 500 meters corresponding to yields of 100, 500, and 1000 kilotons, respectively. During the first year, the area is increased by less than 5 percent for CEPs of greater than 900, 1100, and, 1400 meters corresponding to yields of 100, 500, and 1000 kilotons.

For multiple weapons, the ratio is reduced significantly and, in fact, falls below 1 for CEPs much less than those mentioned in the previous paragraph. This indicates that it is not advantageous to target a reactor with more than one weapon.

It should be noted that, in the case of multiple targeting of the reactor, the increase in area coverage due to targeting inaccuracies was not considered. This, in fact, will make the ratio larger. However, clustering the weapons not targeted at a reactor, which will increase the area coverage due to fallout overlap, was also not considered. This will have the effect of decreasing the ratio. The end result is an offsetting effect.

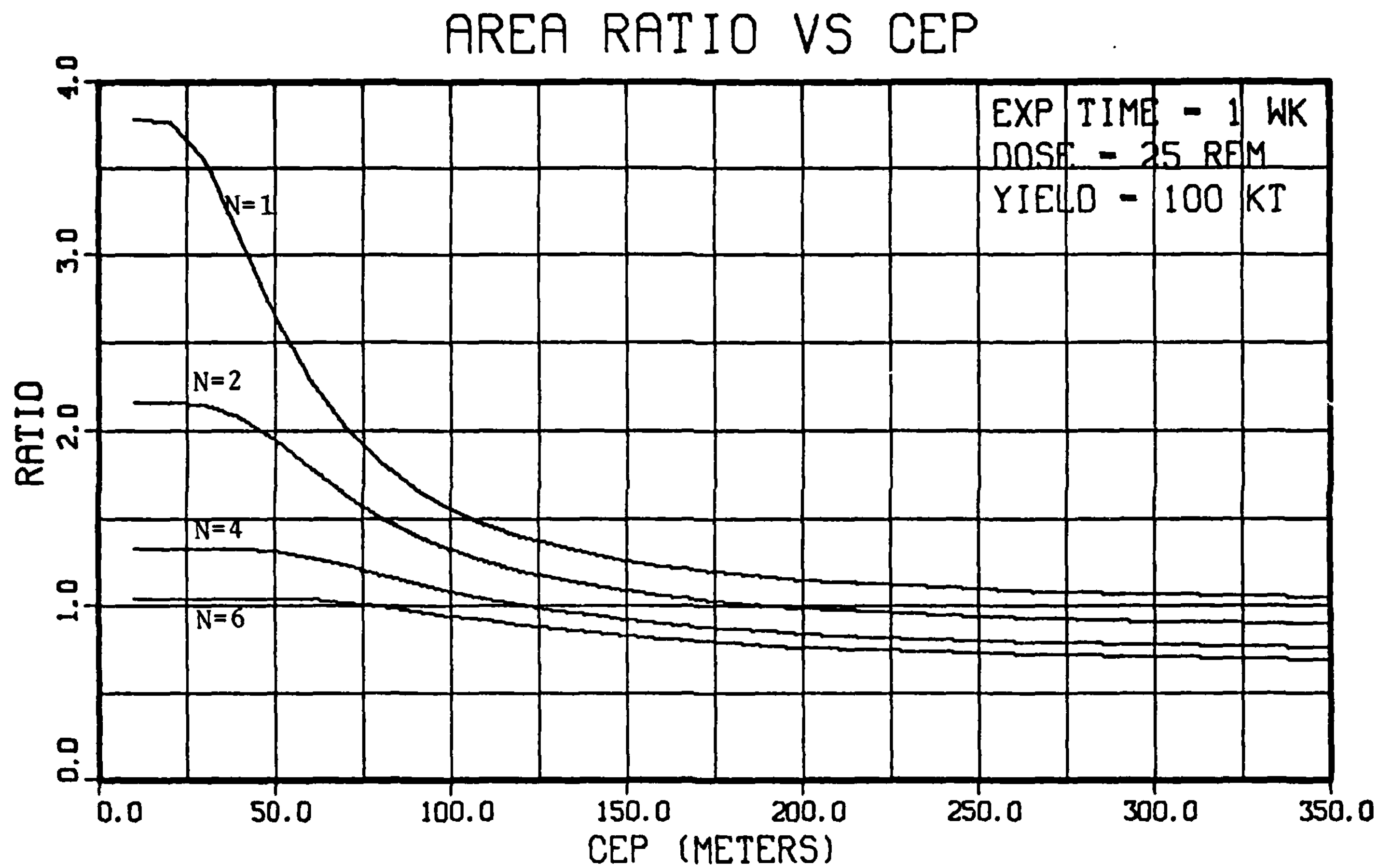

Figure 9. Fallout Effectiveness Ratio from 100 KT Weapons and Nuclear Reactors

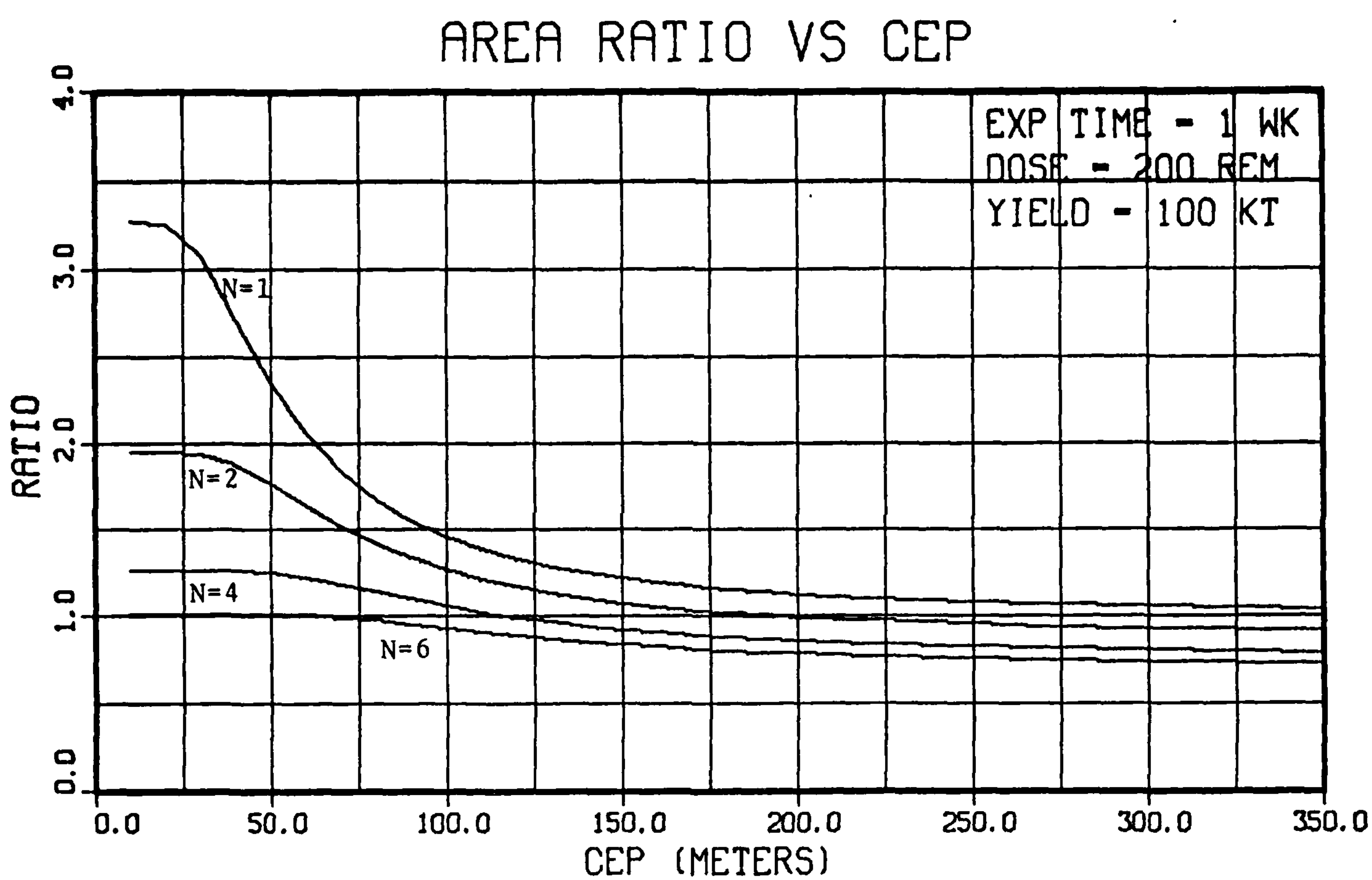

Figure 10. Fallout Effectiveness Ratio from 100 KT Weapons and Nuclear Reactors

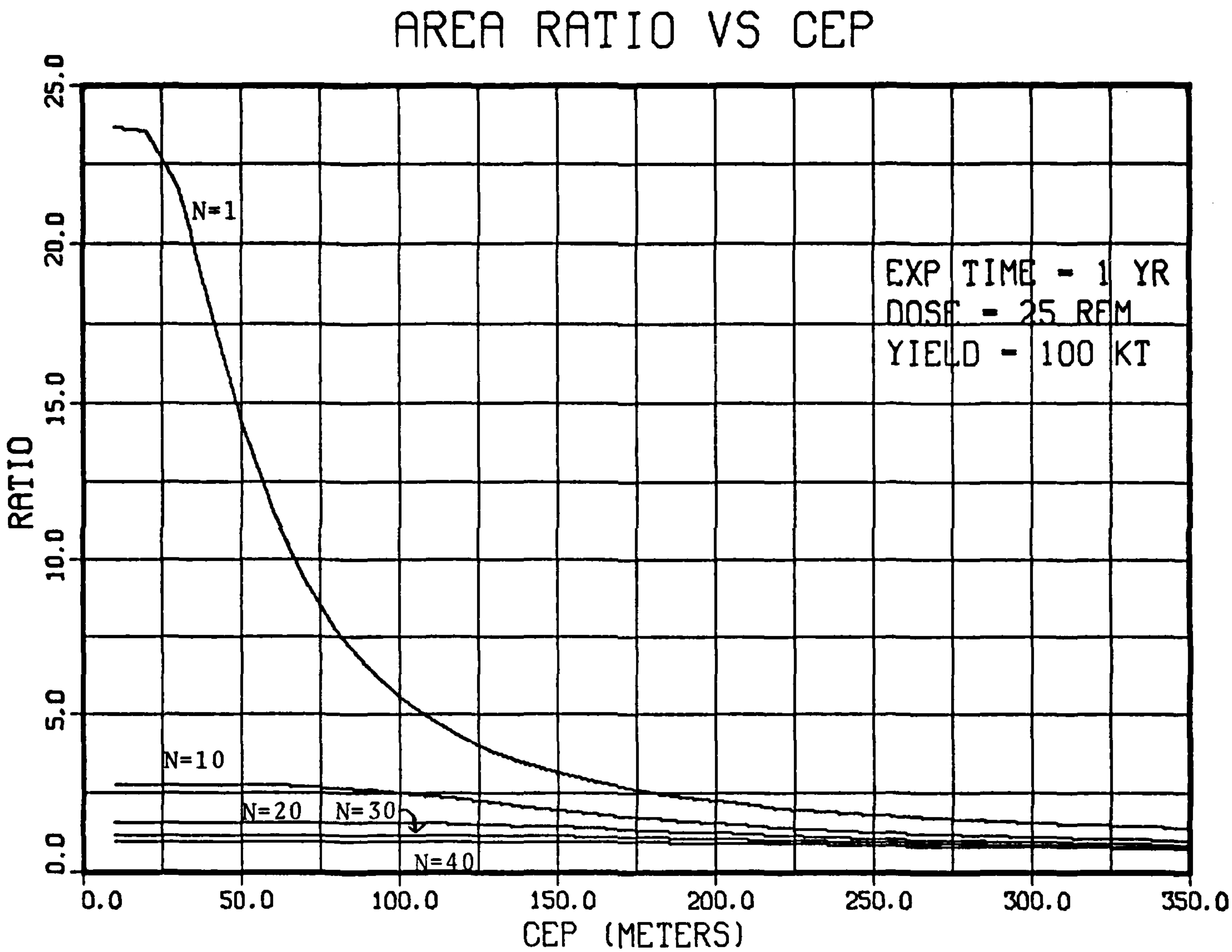

Figure 11. Fallout Effectiveness Ratio from 100 KT Weapons and Nuclear Reactors

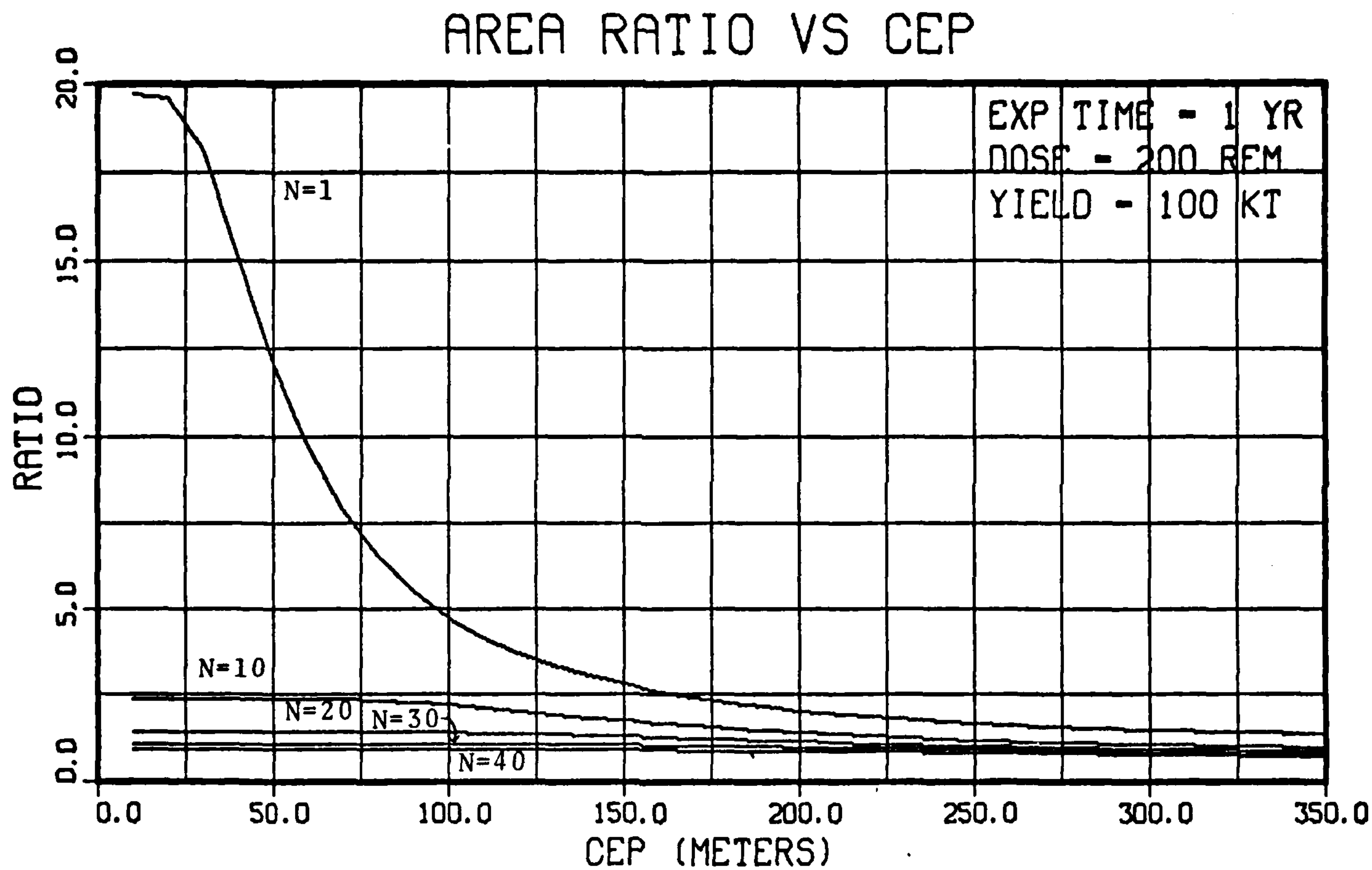

Figure 12. Fallout Effectiveness Ratio from 100 KT Weapons and Nuclear Reactors

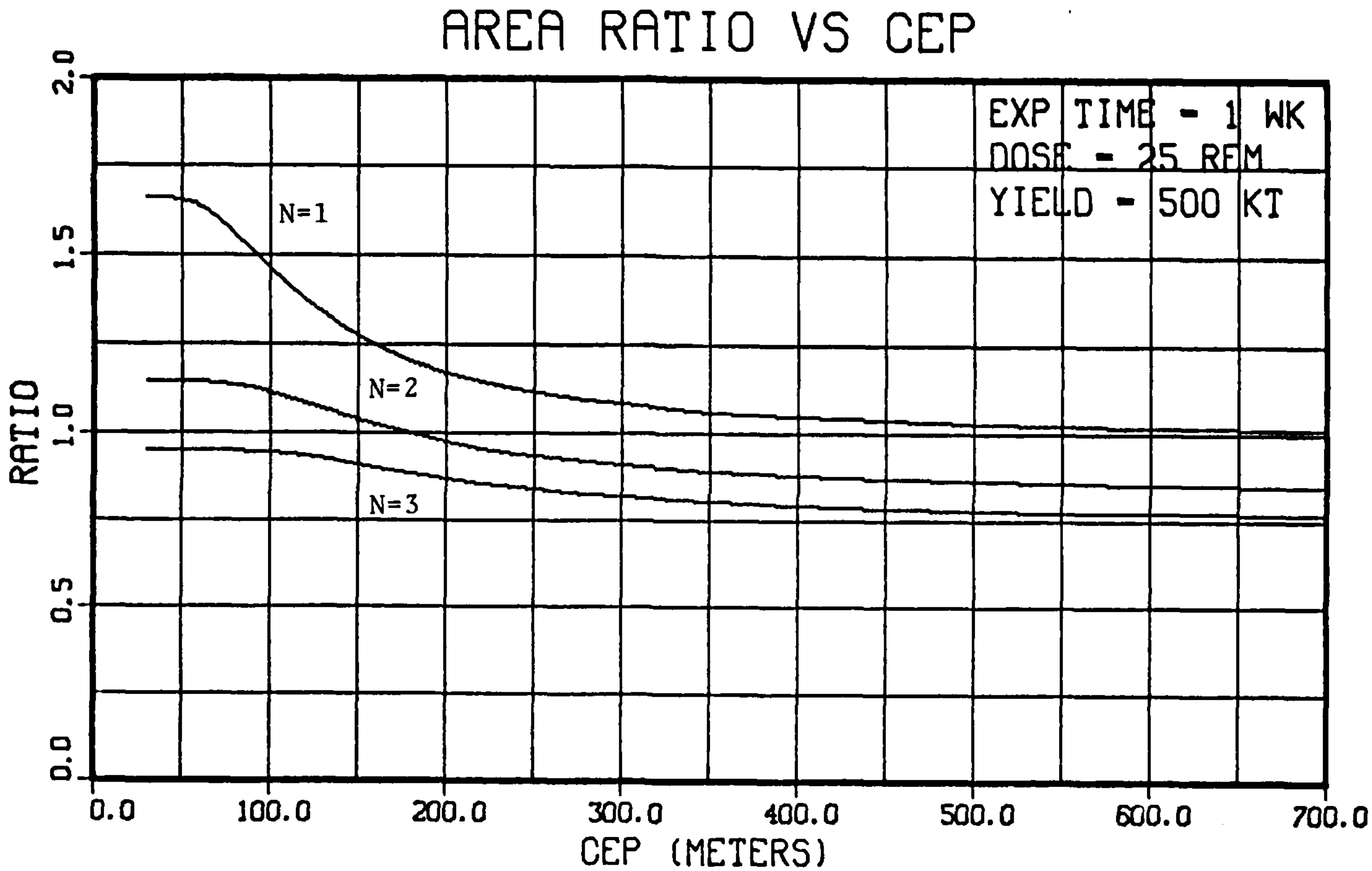

Figure 13. Fallout Effectiveness Ratio from 500 KT Weapons and Nuclear Reactors

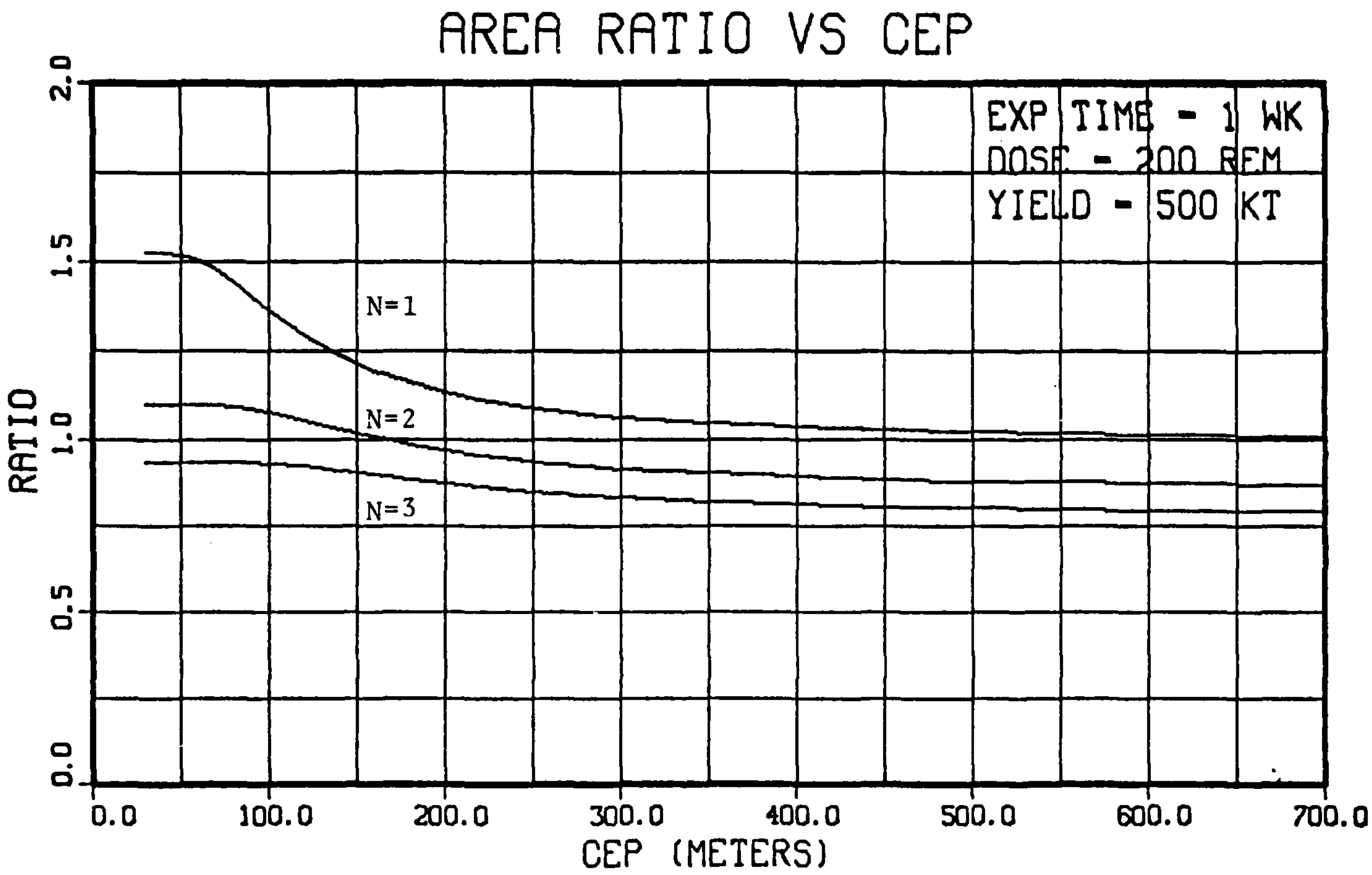

Figure 14. Fallout Effectiveness Ratio from 500 KT Weapons and Nuclear Reactors

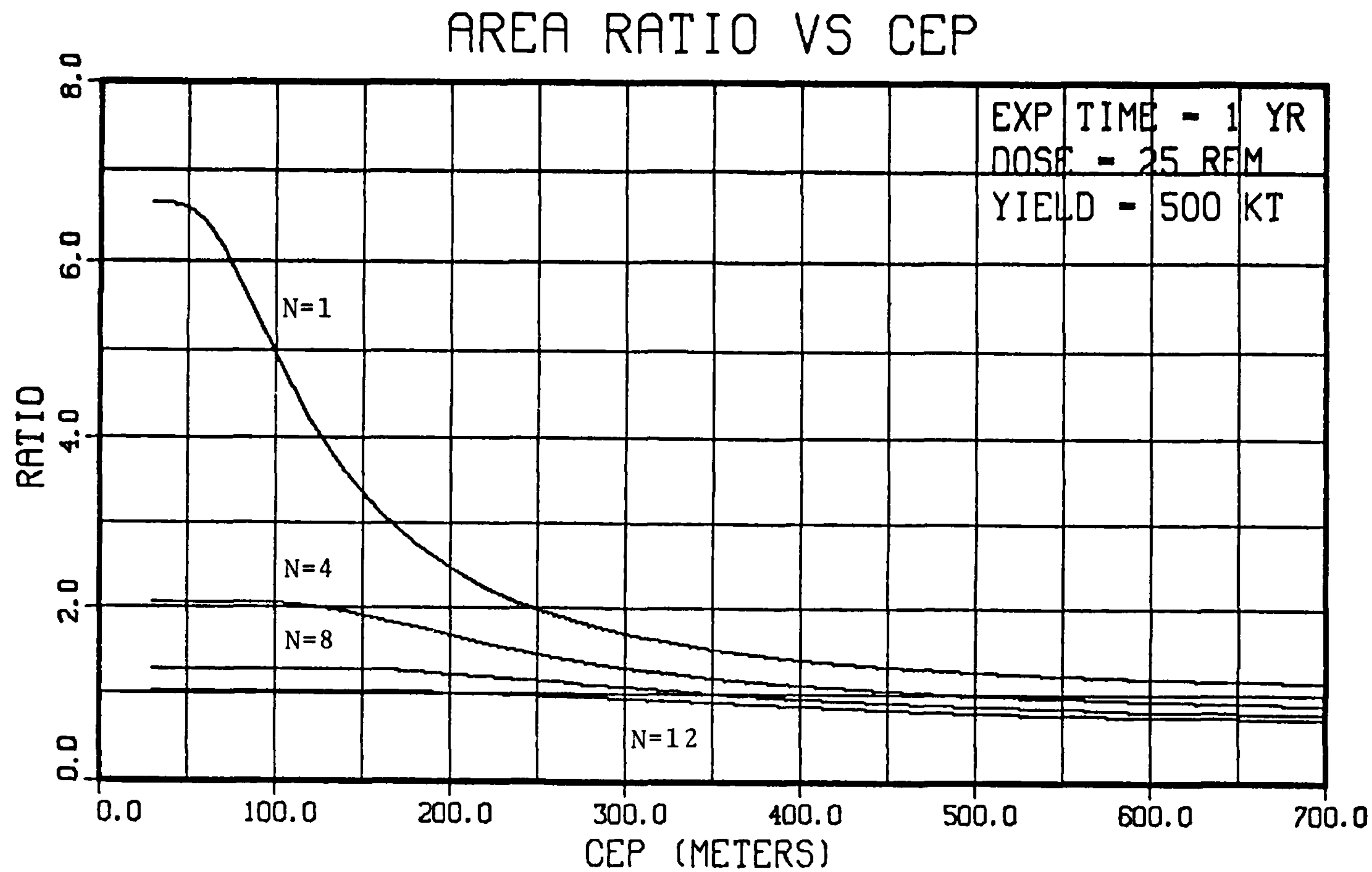

Figure 15. Fallout Effectiveness Ratio from 500 KT Weapons and Nuclear Reactors

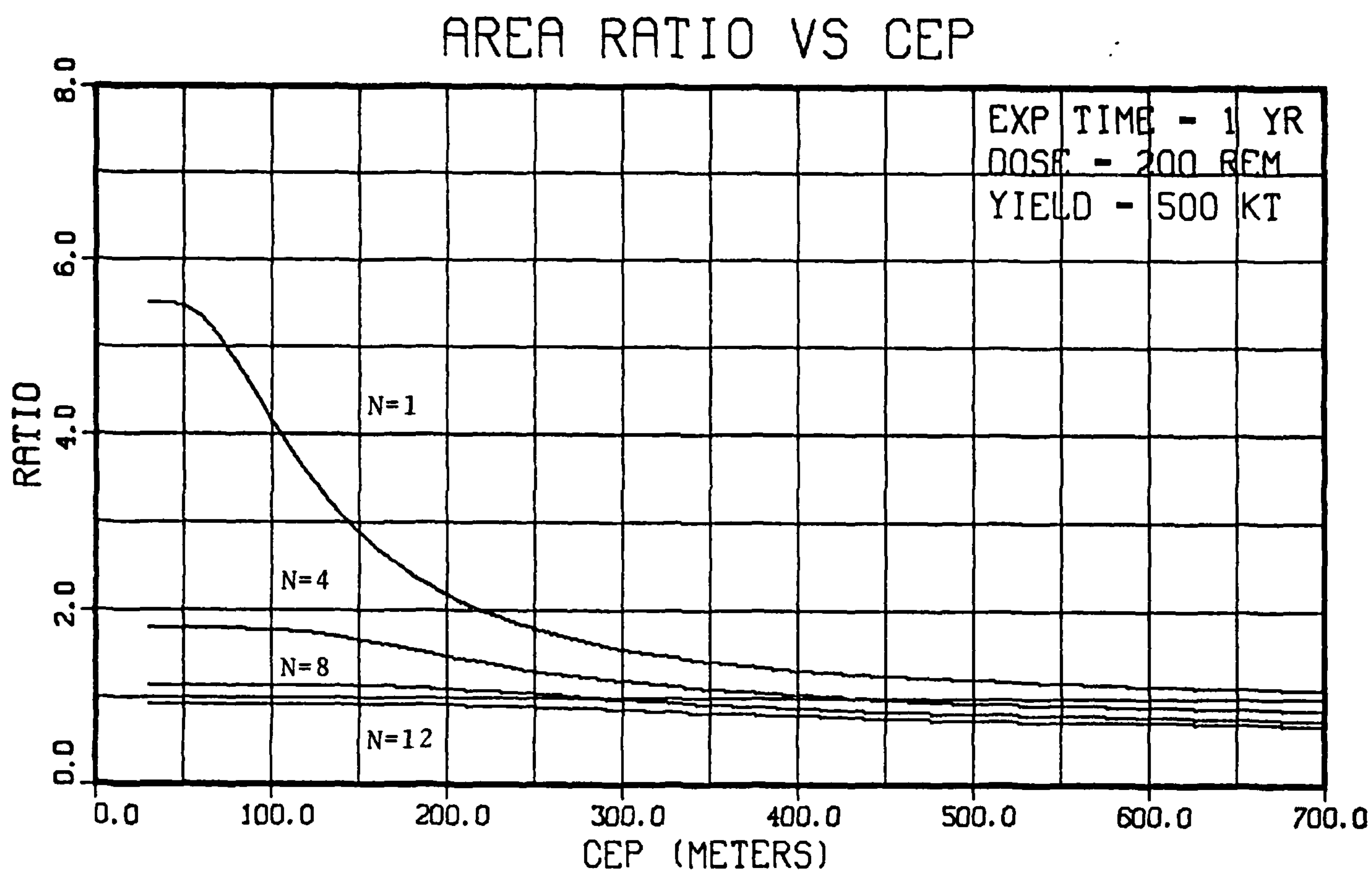

Figure 16. Fallout Effectiveness Ratio from 500 KT Weapons and Nuclear Reactors

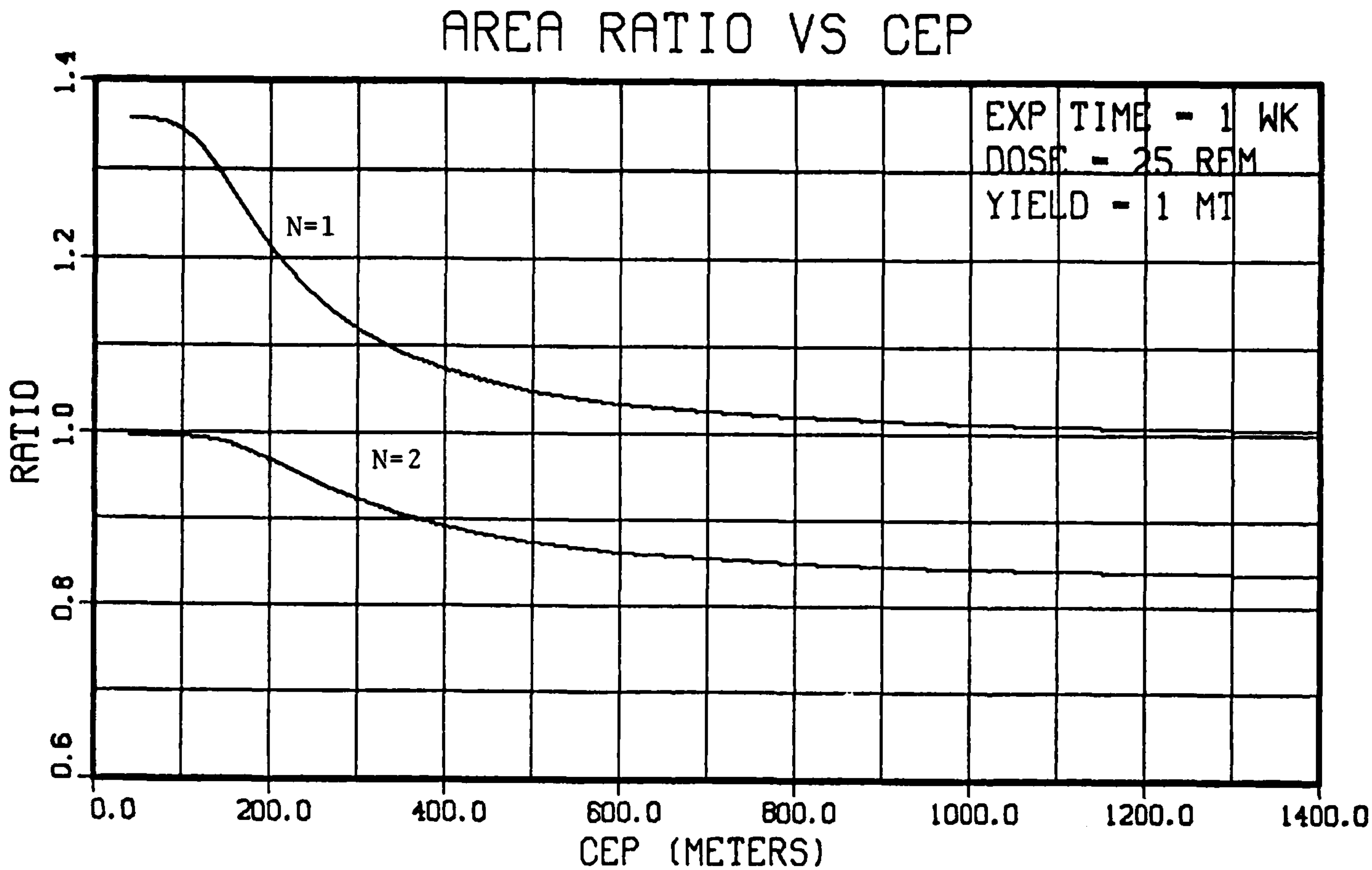

Figure 17. Fallout Effectiveness Ratio from 1 MT Weapons and Nuclear Reactors

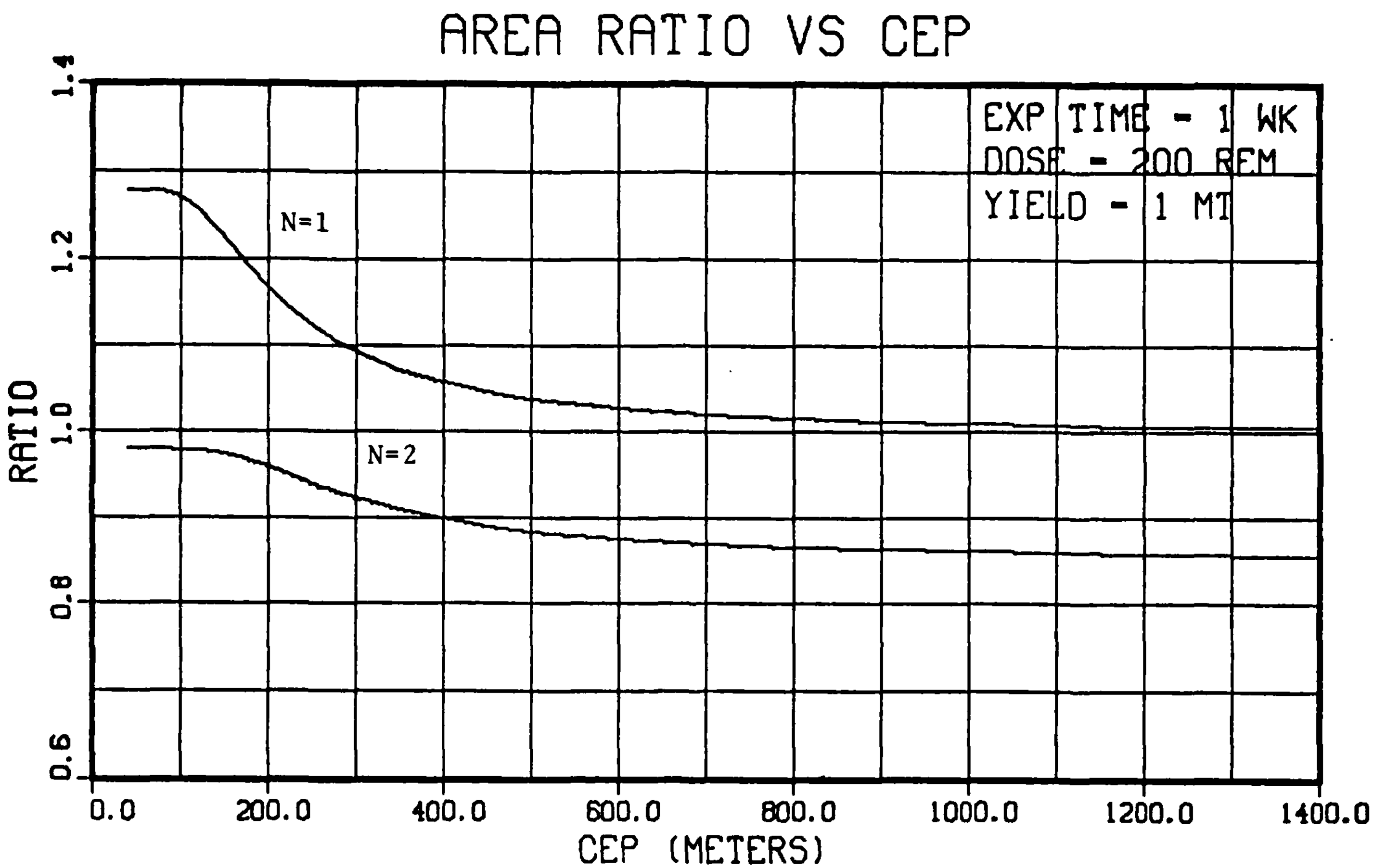

Figure 18. Fallout Effectiveness Ratio from 1 MT Weapons and Nuclear Reactors

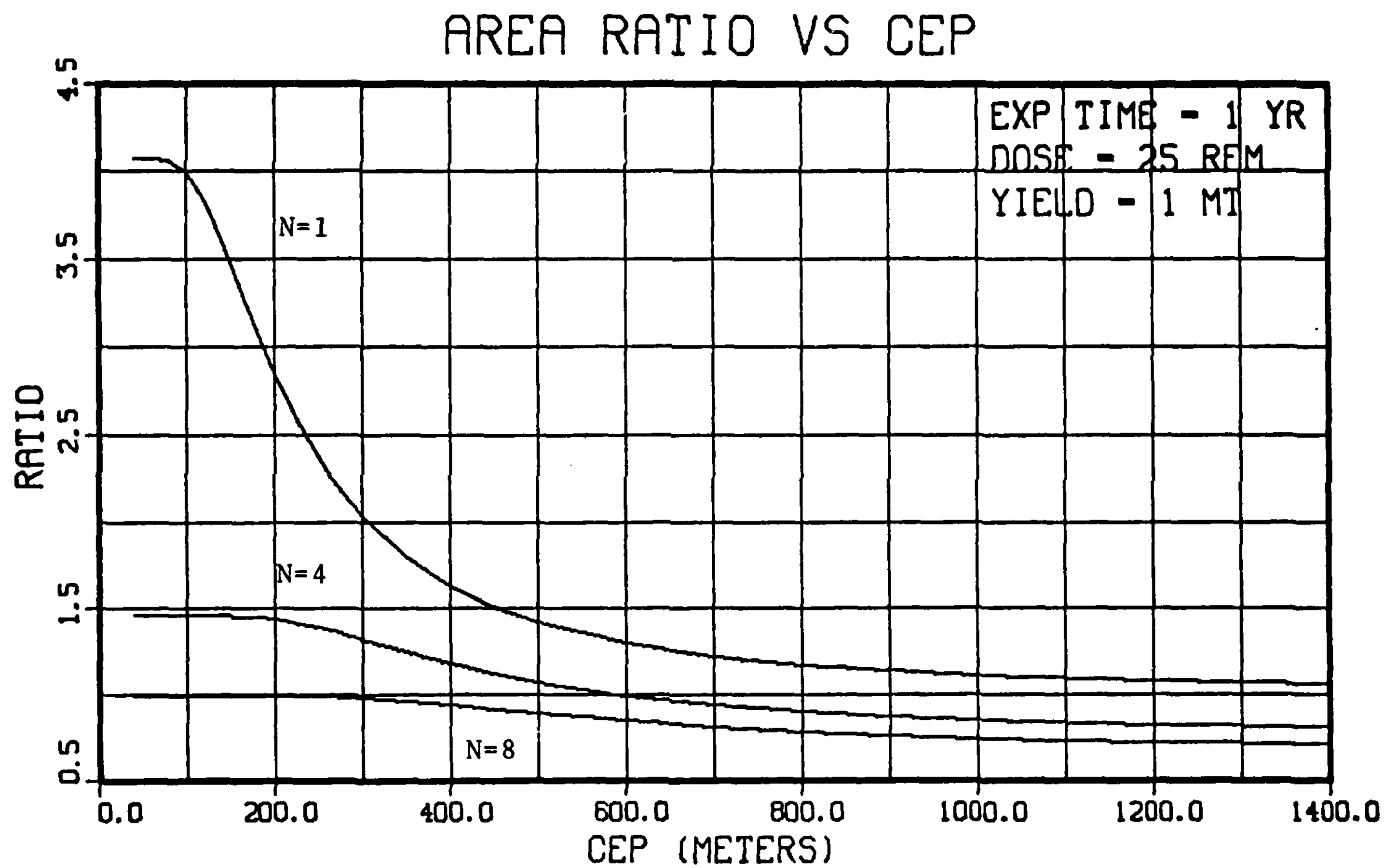

Figure 19. Fallout Effectiveness Ratio from 1 MT Weapons and Nuclear Reactors

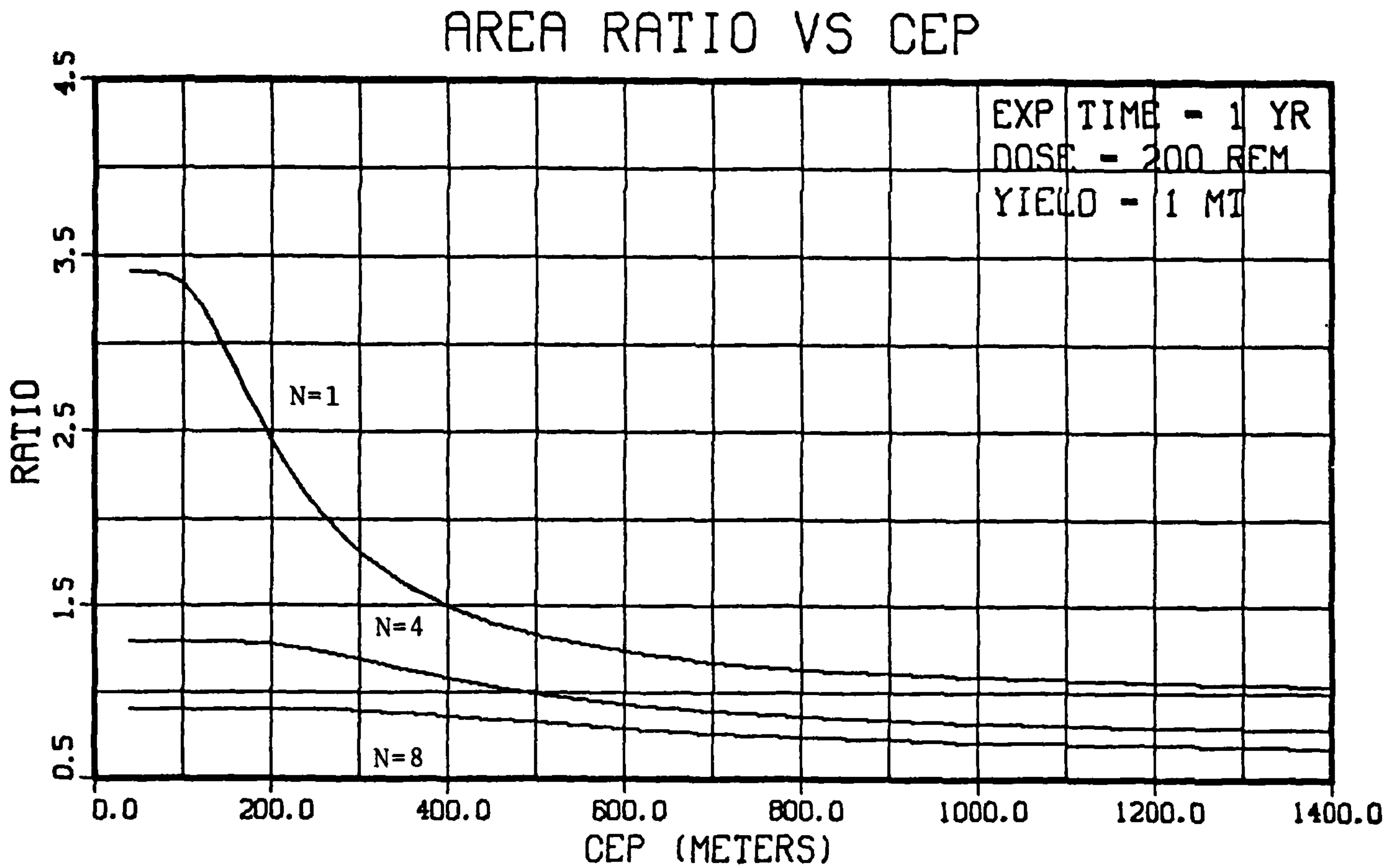

Figure 20. Fallout Effectiveness Ratio from 1 MT Weapons and Nuclear Reactors

V. Fallout from Core Meltdown

The second possible effect of targeting a nuclear reactor is damaging it to the point where the core will melt down. The fallout footprint from a meltdown is significantly smaller than the fallout footprint from a weapon alone. The radioactive fallout from a core meltdown is deposited locally (Ref 6:74). In a reactor meltdown, temperatures are orders of magnitude lower than in a weapon and, therefore, the reactor fallout does not rise to as high an altitude as weapon fallout. Because of the much lower altitude, the fallout returns to the ground in a few tens of miles rather than a few hundred miles, as in the case of weapon fallout. This results in an area of fallout coverage which is much smaller than that of a single weapon, but the intensity of radioactive fallout is higher and remains longer.

Because of the limited area coverage from a core meltdown, it does not appear to be an advantageous method of enhancing radioactive fallout coverage; therefore, area coverage was not computed.

VI. Conclusions and Recommendations

Whether or not light water reactors are attractive targets for enhancing radioactive fallout by vaporizing and lofting the core depends on the accuracy of the weapon. In the case of single weapon targeting of a nuclear reactor, fallout area coverage at early times is increased by less than 5 percent when weapon CEPs are greater than 350 , 400, and 500 meters corresponding to yields of 100, 500, and 1000 kilotons, respectively. At late times, area coverage is increased by less than 5 percent when weapon CEPs are greater than 900, 1100, and 1400 meters corresponding to yields of 100, 500, and 1000 kilotons, respectively.

Targeting reactors with more than one weapon reduces the factor by which fallout coverage is enhanced. Thus, to target a reactor with more than one weapon is counter-productive as a means of enhancing fallout coverage.

Damaging the nuclear reactor to cause a core meltdown does not appear to be an effective way to enhance fallout as the majority of the reactor fallout remains localized.

It is recommended that further study be conducted in the case of multiple weapon targeting of the reactor to determine how much targeting inaccuracies increase the area of fallout coverage. Also, how much will clustering of randomly targeted weapons to produce fallout overlap affect the results?

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APPENDIX A

Probability of Reactor Damage Program

The program presented in this appendix is designed to calculate the probability of vaporizing the core, the probability the core will melt down, and the probability the core will survive if a nuclear weapon is targeted at a light water reactor. The program is called PRBHIT and is written in FORTRAN V.

Input data consists of the various yields in kilotons, the vaporization radii for the specified yields in meters, and the CEPs in meters. PRBHIT is designed to calculate the probabilities for three yields and 25 CEPs, but can easily be adjusted to calculate the probabilities for any number of yields and CEPs.

```
      PROGRAM PRBHIT
      REAL R1(3),Y(3),CEP(25),SIGMA2,PROBV,PROBM,PROBS,
     *PROB1,OP1,R,Z1,PD1,OP2,R2,PROB2,Z2,PD2,SUM,X1,X2
      INTEGER I,J,K,L
C           ---READ YIELDS IN KILOTONS
      READ*,(Y(I),I=1,3)
C           ---READ VAPORIZATION RADII IN METERS
      READ*,(R1(J),J=1,3)
C           ---READ CEPS IN METERS
      READ*,(CEP(K),K=1,25)
      DO 101 I=1,3
      PRINT'(A,T15,A,T27,F8.1,T36,A,//)','1','WEAPON YIELD',
     *Y(I),'KILOTONS'
      PRINT'(T6,A,T20,A,T35,A,T50,A)','CEP (M)','PROB VAP',
     *'PROB MELT','PROB SAFE'
      DO 201 K=1,25
      SIGMA2=CEP(K)**2/(2.0*LOG(2.0))
C           ---CALCULATE PROBABILITY OF VAPORIZATION
      PROBV=1.0-EXP(-.5*R1(I)**2/SIGMA2)
      OP1=30.0
      R=(LOG(OP1/.001)/31.3)**(-4.68165)*Y(I)**(1.0/3.0)
      X1=-.5*R**2/SIGMA2
      IF (X1 .GE. -20.0) THEN
      GO TO 102
      ELSE
      X1=-20.0
      ENDIF
  102 PROB1=1.0-EXP(X1)
      Z1=(LOG(OP1)-2.505)/.4362
      CALL NORMAL(Z1,PD1)
      SUM=0.0
      DO 301 L=1,100
      OP2=OP1+.25
      R2=(LOG(OP2/.001)/31.3)**(-4.68165)*Y(I)**(1.0/3.0)
      X2=-.5*R2**2/SIGMA2
```

```
      IF (X2 .GE. -20.0) THEN
      GO TO 103
      ELSE
      X2=-20.0
      ENDIF
  103 PROB2=1.0-EXP(X2)
      Z2=(LOG(OP2)-2.505)/.4362
      CALL NORMAL(Z2,PD2)
      SUM=SUM+(PROB2-PROB1)*((PD1+PD2)/2.0)
      OP1=OP2
      PD1=PD2
      PROB1=PROB2
  301 CONTINUE
C            ---CALCULATE PROBABILITY OF MELTDOWN
      PROBM=EXP(-.5*R1(I)**2/SIGMA2)-EXP(X1)+SUM
C            ---CALCULATE PROBABILITY OF CORE SURVIVAL
      PROBS=1.0-(PROBV+PROBM)
      PRINT'(/,T5,F8.2,T17,F10.6,T32,F10.6,T47,F10.6)',CEP(K)
     *,PROBV,PROBM,PROBS
  201 CONTINUE
  101 CONTINUE
      END
```

```
      SUBROUTINE NORMAL(Z,F)
      REAL Z,F
      IF (Z .GE. 0.0) THEN
      F=1.0-.5*(1.0/(1.0+.196854*Z+.115194*Z**2+.000344*Z**3
     *+.019527*Z**4))**4
      ELSE
      F=.5*(1.0/(1.0+.196854*ABS(Z)+.115194*ABS(Z)**2+.000344*
     *ABS(Z)**3+.019527*ABS(Z)**4))**4
      ENDIF
      END
```

APPENDIX B

Probability of Reactor Damage for Various Yields and CEPs

This appendix provides a listing of the probabilities of vaporizing the reactor core, a core meltdown, and the core surviving a nuclear detonation for weapons of 100, 500, and 1000 kiloton yields with CEPs ranging from 10 to 2500 meters.

WEAPON YIELD 100.0 KILOTONS

CEP (M)	PROB VAP	PROB MELT	PROB SAFE
10.00	1.000000	-.000000	.000000
20.00	.996412	.003588	.000000
30.00	.918100	.081900	.000000
40.00	.755251	.244749	.000000
50.00	.593761	.406239	.000000
60.00	.465041	.534959	.000000
70.00	.368463	.631537	.000000
80.00	.296636	.703364	.000000
90.00	.242725	.757275	.000000
100.00	.201646	.798354	.000000
200.00	.054745	.944492	.000762
300.00	.024712	.934238	.041049
400.00	.013977	.820320	.165704
500.00	.008968	.674772	.316260
600.00	.006236	.544350	.449414
700.00	.004585	.439871	.555543
800.00	.003513	.358953	.637535
900.00	.002776	.296564	.700660
1000.00	.002250	.248124	.749626
1250.00	.001440	.167018	.831542
1500.00	.001000	.119253	.879746
1750.00	.000735	.089107	.910158
2000.00	.000563	.068978	.930459
2250.00	.000445	.054916	.944640
2500.00	.000360	.044724	.954916

WEAPON YIELD   500.0 KILOTONS

CEP (M)	PROB VAP	PROB MELT	PROB SAFE
10.00	1.000000	-.000000	.000000
20.00	1.000000	-.000000	.000000
30.00	.999999	.000001	.000000
40.00	.999473	.000527	.000000
50.00	.992021	.007979	.000000
60.00	.965085	.034915	.000000
70.00	.914972	.085028	.000000
80.00	.848488	.151512	.000000
90.00	.774861	.225139	.000000
100.00	.701128	.298872	.000000
200.00	.260614	.739386	.000000
300.00	.125579	.874332	.000089
400.00	.072705	.922042	.005253
500.00	.047161	.918133	.034706
600.00	.032992	.870208	.096800
700.00	.024346	.795940	.179713
800.00	.018694	.712734	.268572
900.00	.014800	.631415	.353785
1000.00	.012005	.557090	.430905
1250.00	.007700	.408997	.583303
1500.00	.005353	.306978	.687669
1750.00	.003936	.236611	.759454
2000.00	.003015	.186963	.810022
2250.00	.002383	.150985	.846632
2500.00	.001931	.124235	.873834

WEAPON YIELD 1000.0 KILOTONS

CEP (M)	PROB VAP	PROB MELT	PROB SAFE
10.00	1.000000	-.000000	.000000
20.00	1.000000	-.000000	.000000
30.00	1.000000	-.000000	.000000
40.00	1.000000	-.000000	.000000
50.00	1.000000	.000000	.000000
60.00	.999965	.000035	.000000
70.00	.999473	.000527	.000000
80.00	.996909	.003091	.000000
90.00	.989604	.010396	.000000
100.00	.975244	.024756	.000000
200.00	.603340	.396660	.000000
300.00	.336991	.663008	.000000
400.00	.206395	.793364	.000241
500.00	.137524	.857644	.004832
600.00	.097640	.877746	.024614
700.00	.072705	.861599	.065696
800.00	.056154	.819589	.124257
900.00	.044636	.762991	.192373
1000.00	.036311	.700677	.263012
1250.00	.023394	.551437	.425170
1500.00	.016304	.431676	.552020
1750.00	.012005	.341799	.646196
2000.00	.009204	.275010	.715786
2250.00	.007279	.224926	.767795
2500.00	.005900	.186791	.807308

WEAPON YIELD 1000.0 KILOTONS

CEP (M)	PROB VAP	PROB MELT	PROB SAFE
10.00	1.000000	-.000000	.000000
20.00	1.000000	-.000000	.000000
30.00	1.000000	-.000000	.000000
40.00	1.000000	-.000000	.000000
50.00	1.000000	.000000	.000000
60.00	.999965	.000035	.000000
70.00	.999473	.000527	.000000
80.00	.996909	.003091	.000000
90.00	.989604	.010396	.000000
100.00	.975244	.024756	.000000
200.00	.603340	.396660	.000000
300.00	.336991	.663008	.000000
400.00	.206395	.793364	.000241
500.00	.137524	.857644	.004832
600.00	.097640	.877746	.024614
700.00	.072705	.861599	.065696
800.00	.056154	.819589	.124257
900.00	.044636	.762991	.192373
1000.00	.036311	.700677	.263012
1250.00	.023394	.551437	.425170
1500.00	.016304	.431676	.552020
1750.00	.012005	.341799	.646196
2000.00	.009204	.275010	.715786
2250.00	.007279	.224926	.767795
2500.00	.005900	.186791	.807308

APPENDIX C

Program SMEAR1

This program provides the fallout footprint of selected dose rates or doses for weapons alone or a weapon along with the core of a reactor. As listed, the program will provide footprints for a single weapon or a single weapon and reactor. For multiple targeting of a reactor with weapons of the same yield, only line 37 of the program needs to be changed by multiplying the SC value by the number of weapons.

```
      PROGRAM SMEAR1
C                      ---19 DECEMBER 1981--
      DIMENSION D(5),CL(7)
      COMMON C(7),AL(2),BT(2),FR(2)
      COMMON TC,SIGO,SIGH,SHR,SC,VX,TB,TM,TF,TD,M,MD
      COMMON FO,MB,Q,YL,WD,XD,YD,MR,RC,PW,OL
C                      ---M=0 FOR WSEG,M=1 FOR AFIT
C                      ---MD=0 FOR RATE,MD=1 FOR DOSE
C                      ---IF(M=0 & MD=1): WSEG BIO DOSE
C                      ---IF(M=0 & MD>1): WSEG WAY-WIGNER DOSE
C                      ---N= NUMBER OF CONTOURS
C                      ---LP=0 PRINT ONLY,=1 PRINT & PUNCH
C                      ---MR=0 FOR WEAPON, MR=1 FOR WEAPON AND REACTOR
C                      ---TD=DURATION AFTER TA IN HOURS
C                      ---TD<0. = DURATION AFTER BURST IN HOURS
      READ 5,M,MD,N,LP,MR,TD
 5    FORMAT(5I3,F7.1)
C                      ---READ CONTOURS WANTED R/HR OR R
          DO 10 I = 1,N
 10       READ 15, D(I)
 15       FORMAT (F7.1)
C                      ---YM=YIELD IN MT.
C                      ---FF=FISSION FRACTION
C                      ---VX=EFFECTIVE MEAN WIND MILES/HR
C                      ---SHR=PERPENDICULAR WIND SHEAR HR-1
C                      ---OL=AVERAGE OPERATING CAPACITY OF REACTOR
C                      ---PW=THERMAL POWER OF REACTOR IN MEGAWATTS
      READ 20,YM,FF,VX,SHR,OL,PW
 20   FORMAT(5F8.4,F10.4)
C                      ---MB=NUMBER OF BURSTS ALONG A
C                      ---WD=LINE MILES WIDE AT GZ
      READ 25,MB,WD
 25   FORMAT(I4,F7.2)
C                      ---IF WSEG SET SC =2E+06
      IF(M.EQ.0) SC=2.000E+06*FF*YM
```

```
C                     ---IF AFIT SET SC =2.35E+06
      IF(M.GT.0) SC=2.354E+06*FF*YM
C                     ---RC REACTOR CONSTANT
      RC=3.01509*FW*OL
C                     ---YIELD DEPENDENT CONSTANTS:
C                     ---HC IN KILOFEET AFTER WSEG
      HC=44.+6.1*ALOG(YM)-.205*(ALOG(YM)+2.42)*ABS(ALOG(YM)+2.42)
C                     ---SIGH & SIGO IN STATUTE MILES
      SIGH = .18*HC/5.28
      SIGO = EXP(.70+ALOG(YM)/3. - 3.25/(4.+(ALOG(YM)+5.4)**2))
C                     ---TC IN HOURS
      TC = 1.0573*(12.*HC/60.-2.5*HC*HC/3600.)*(1.-.5*EXP(-HC*HC/625.))
C                     ---SET ALPHA & BETA FOR WSEG CALC.
      AL(1) = ALOG(44.)
      BT(1) = .690
      FR(1) = 1.
C                     ---IF WSEG CALC. SKIP TO 60
      IF (M.EQ.0) GOTO 60
      READ 30,RO,BT(1),FR(1)
   30 FORMAT(3F7.3)
      AL(1)=ALOG(RO) + 3.*BT(1)**2
      AL(2)=ALOG(RO) + 2.*BT(1)**2
      BT(2) = BT(1)
      FR(2) = 1.-FR(1)
      ZK = HC*1.609/5.28
   32 READ 35,Z,(C(J),J=1,4)
      READ 35,Z,(C(J),J=5,7)
   35 FORMAT(F5.1,4E11.5)
      IF (Z.GT.ZK) GOTO 45
C                     ---Z < HC, STORE C IN CLAST
      DO 40 I = 1,7
   40 CL(I) = C(I)
C                     ---GO BACK & READ ANOTHER ALT.
      GOTO 32
C                     ---HC IS BRACKETED, INTERPOLATE
```

```
 45   DO 50 I = 1,7
 50   C(I) = C(I)-(C(I)-CL(I))*(Z-ZK)/.2
      PRINT 55
 55   FORMAT (' AFIT CALCULATION')
C                    ---IF WSEG CALC.,PRINT THAT
 60   IF (M.EQ.0) PRINT 65
 65   FORMAT (' WESG CALCULATION')
C                    ---PRINT OUTPUT HEADINGS
      PRINT 70,YM,FF
 70   FORMAT (' YIELD = ',F8.3,' MT. FISSION FRACTION = ',F5.2)
      IF (MR.EQ.1) PRINT 71,PW,OL
 71   FORMAT (' REACTOR THERMAL POWER = ',F7.1,' MEGAWATTS AVERAGE OPER
     1ATING CAPACITY = ',F5.2)
      IF (MB.EQ.1.AND.MR.EQ.0) PRINT 75
 75   FORMAT (' SINGLE BURST')
      IF (MB.EQ.1.AND.MR.EQ.1) PRINT76
 76   FORMAT (' SINGLE BURST WITH REACTOR')
      IF (MB.GT.1) PRINT 80,MB,WD
 80   FORMAT (I5,' BURSTS ALONG A LINE',F5.0,' MILES LONG')
      PRINT 85, VX,SHR
 85   FORMAT (' WIND = ',F5.1,' MPH. WIND SHEAR = ',F6.3,' HR-1')
      PRINT 90
 90   FORMAT (' ACTIVITY-SIZE DISTRIBUTION IS LOGNORMAL ')
      PER = FR(1)*100.
      A = EXP(AL(1))
      B = EXP(BT(1))
      PRINT 95,PER, A,B
 95   FORMAT(F7.2,' % HAS AN ALPHA = LN(',F5.2,') AND A BETA = LN(',F5.3
     1,')')
      IF(FR(1).EQ.1.) GOTO 100
      PER = FR(2)*100.
      A = EXP(AL(2))
      IF (M.EQ.0) A = AL(1)
      B = EXP(BT(2))
      PRINT 95,PER,A,B
```

```
C                        ---FIND MAXIMUM OF G(T) & CALL IT TM.
 100   CALL GMAX
      XM= TM*VX
      Z=WD/(2.*SIGY(XM))
      FO=CN(Z)-CN(-Z)
      IF(MB.EQ.1.AND.MR.EQ.0) DMAX=SC*G(TM)/(VX*2.5066*SIGY(XM))
      IF(MB.EQ.1.AND.MR.EQ.1) DMAX=(SC+RC*2.5648)*G(TM)/(VX*2.5066*SIGY(
     1XM))
      IF(MB.GT.1) DMAX=SC*G(TM)*FLOAT(MB)*FO/(VX*WD)
      PRINT 105,DMAX,XM
 105  FORMAT (' MAX. DOSE(RATE) IS ',F9.2,' AT ',F8.2,' MILES.')
      IF(MD.GT.0.AND.TD.EQ.0.) PRINT 107
 107  FORMAT (' DOSE IS COMPUTED TO INFINITY.')
      IF(MD.GT.0.AND.TD.GT.0.) PRINT 108,TD
 108  FORMAT (' DOSE COMPUTED TO ',F7.1,' HOURS AFTER ARRIVAL.')
      TT=-TD
      IF (MD.GT.0.AND.TD.LT.0.) PRINT 109, TT
 109  FORMAT (' DOSE COMPUTED TO ',F7.1,' HOURS AFTER BURST.')
C                        ---OUTER DO LOOP ON CONTOURS
           DO 150 K=1,N
           Q=D(K)
C                        ---FIND UPSLOPE BEGINING OF CONTOUR
           CALL UPHILL
C                        ---RETURN WITH A VALUE OF TB
           IF (TB.EQ.-99.) GOTO 110
C                        ---FIND DOWNSLOPE END OF CONTOUR
           CALL DWHILL
C                        ---RETURN WITH VALUE FOR TF
C                        ---DIVIDE HOT LINE INTO 25 STEPS
           DT =(TF-TB)*.04
C                        ---PRINT CONTOUR TITLE
 110        IF (MD.EQ.O) PRINT 115, D(K)
 115  FORMAT (' COORDINATES FOR ',F7.1,'R/HR ISORATE LINE')
            IF (MD.NE.O) PRINT 120, D(K)
 120  FORMAT (' COORDINATES FOR ',F7.1,' R ISODOSE LINE')
```

```
            IF (TB.EQ.-99.) GOTO 150
                  ---FIND X,Y VALUES FOR EACH STEP
                  ---SET YL FOR FIRST PASS THRU YVALUE
             YL=WD/2.
                  ---LOOP THRU STEPS TO FIND X & Y
               DO 135 I = 1,25
               T = FLOAT(I-1)*DT   + TB
               XD = VX*T
                  ---DHL IS DOSE ON HOT LINE
               DHL = SC*G(T)/VX
               IF(MR.EQ.1.AND.MD.EQ.0) DHL = DHL+RC*2.5648*G(T)/VX
               IF(MB.EQ.1) GOTO 125
               Z = WD/(2.*SIGY(XD))
               FO = CN(Z)-CN(-Z)
 125           IF (MB.EQ.1) DHL=DHL/(2.5066*SIGY(XD))
               IF (MB.GT.1) DHL=DHL*FLOAT(MB)*FO/WD
               IF (MD.NE.0.AND.MR.EQ.0) DHL=DHL*BI(T)
               IF (MD.NE.0.AND.MR.EQ.1) DHL=DHL*BI(T)+RC*RD(T)*G(T)/(VX
     1         *2.5066*SIGY(XD))
                  ---Q IS TEMP. STORAGE IN COMMON
               Q=D(K)/DHL
                  ---YVALUE SEARCHES FOR Y GIVEN THIS X
               CALL YVALUE
 130           PRINT 140,I,XD,YD
               IF(LP.EQ.1) PUNCH 140,I,D(K),XD,YD
 135           CONTINUE
 140           FORMAT (I5,3F8.1)
                  ---PRINT THE FINAL POINT
            XD = VX*TF
            YD = 0.
            PRINT 140,26,XD,YD
            IF(LP.EQ.1) PUNCH 140,I,D(K),XD,YD
 150        CONTINUE
        STOP
        END
```

```
      SUBROUTINE GMAX
C                   ---FIND MAXIMUM IN G(T)
      COMMON C(7),AL(2),BT(2),FR(2)
      COMMON TC,SIGO,SIGH,SHR,SC,VX,TB,TM,TF,TD,M,MD
      COMMON FO,MB,Q,YL,WD,XD,YD,MR,RC,PW,OL
            DO 4 J=1,100
            T=FLOAT(J-1)*.1
            DM=G(T)
            IF (J.EQ.1) GOTO  3
C                   ---CLIMB G(T) TILL IT DESCENDS
            IF (DM.LT.DL) GOTO  5
 3          DL=DM
 4          CONTINUE
C                   ---NO INTERPOLATION, DT= .1
 5    TM=T-.1
      RETURN
      END
```

```
      SUBROUTINE UPHILL
C                    ---FIND BEGINING OF THIS CONTOUR ON HOT LINE
      COMMON C(7),AL(2),BT(2),FR(2)
      COMMON TC,SIGO,SIGH,SHR,SC,VX,TB,TM,TF,TD,M,MD
      COMMON FO,MB,Q,YL,WD,XD,YD,MR,RC,PW,OL
C                    ---TB = -99 IS A FLAG FOR TB>TM
      TB = -99.
C                    ---TQ = INITIAL TIME FOR WSEG
      TQ = -(3.*SIGO)/VX
C                    ---INITIAL TIME FOR AFIT IS 0
      IF (M.NE.0) TQ = 0.
      T=TQ
C                    ---DT FOR WSEG FOR T < 3 SIGMA O
      DT = .1*ABS(TQ)
      DL = 0.
C                    ---DL IS TEMP. STORAGE FOR LAST VALUE
          DO 2 J=2,100
C                    ---RESET DT FOR WSEG OR SET IT FOR AFIT
          IF(T.GE.ABS(TQ)) DT=.01
          T = T + DT
          X = T*VX
          Z = WD/(2.*SIGY(X))
          FO = CN(Z) - CN(-Z)
          DM = SC*G(T)/VX
          IF(MR.EQ.1.AND.MD.EQ.0) DM=DM+RC*2.5648*G(T)/VX
          IF(MB.EQ.1) DM=DM/(2.5066*SIGY(X))
          IF(MB.GT.1) DM=DM*FLOAT(MB)*FO/WD
          IF(MD.NE.0.AND.MR.EQ.0) DM=DM*BI(T)
          IF(MD.NE.0.AND.MR.EQ.1) DM=DM*BI(T)+RC*RD(T)*G(T)/(VX*2.5066*
     1    SIGY(X))
C                    ---Q HAS CURRENT VALUE OF D(K)
          IF (DM.GE.Q) GOTO 3
C                    ---IF T>TM THEN D(K) > PEAK VALUE
          IF(T.GT.TM) RETURN
          DL=DM
```

```
2         CONTINUE
      RETURN
C                      ---INTERPOLATE
3     DLT = DT*(DM-Q)/(DM-DL)
      TB=T-DLT
      RETURN
      END
```

```
      SUBROUTINE DWHILL
C                 ---FIND END OF THIS CONTOUR ON HOT LINE
      COMMON C(7),AL(2),BT(2),FR(2)
      COMMON TC,SIGO,SIGH,SHR,SC,VX,TB,TM,TF,TD,M,MD
      COMMON FO,MB,Q,YL,WD,XD,YD,MR,RC,PW,OL
      IF (MB.EQ.1) DT = .1
      IF (MB.GT.1) DT = .5
C                 ---JL SETS BEGINING OF DO LOOP SEARCH
      JL = TM/DT + 2.
C                 ---GO DOWN G(T) FROM MAX TO FIND D(K)
            DO 4 J = JL,500
            T = FLOAT(J-1)*DT
            X = T*VX
            Z = WD/(2.*SIGY(X))
            FO = CN(Z)-CN(-Z)
            DN = SC*G(T)/VX
            IF(MR.EQ.1.AND.MD.EQ.0) DN=DN+RC*2.5648*G(T)/VX
            IF(MB.EQ.1) DN=DN/(2.5066*SIGY(X))
            IF (MB.GT.1) DN=DN*FLOAT(MB)*FO/WD
            IF(MD.NE.0.AND.MR.EQ.0) DN=DN*BI(T)
            IF(MD.NE.0.AND.MR.EQ.1) DN=DN*BI(T)+RC*RD(T)*G(T)/(VX*2.5066
     1      *SIGY(X))
C                 ---IF FIRST PASS SKIP TO CONTINUE
            IF (J.EQ.JL) GOTO 3
C                 ---Q IS TEMP. STORAGE FOR D(K)
            IF(Q.GT.DN) GOTO 5
 3          DL = DN
 4          CONTINUE
C                 ---INTERPOLATE
 5    DLT = DT*(Q-DN)/(DL-DN)
      TF =  T -DLT
      RETURN
      END
```

```
      FUNCTION G(T)
C                      ---COMPUTES G(T) FOR AFIT OR WSEG
      COMMON C(7),AL(2),BT(2),FR(2)
      COMMON TC,SIGO,SIGH,SHR,SC,VX,TB,TM,TF,TD,M,MD
      COMMON FO,MB,Q,YL,WD,XD,YD,MR,RC,PW,OL
C                      ---IF WSEG GO TO 4
      IF (M.EQ.0) GOTO 4
C                      ---T=0 IS SINGULARITY. MUST START T=.1
      TZ=.1
      IF (T.LT.TZ) S = TZ
      IF(T.GE.TZ) S=T
C                      ---AFIT FORMULA FOR RADIUS IN METERS
      R=C(1)/(S**5)+C(2)/(S**4)+C(3)/(S**3)
      R=R+C(4)/(S*S)+C(5)/S+C(6)+C(7)/SQRT(S)
C                      ---CONVERT TO MICRONS
      R = R*1.E+06
C                      ---INITIALIZE A
      A = 0.
C                      ---COMPUTE ACTIVITY-SIZE FUNCTION
      DO 1 L = 1,2
      P = (ALOG(R) - AL(L))/BT(L)
      A = A+FR(L)*EXP(-.5*P*P)/(SQRT(6.283)*BT(L)*R)
      IF (FR(1).EQ.1.) GOTO 2
 1    CONTINUE
C                      ---DR/DT IS DERIVATIVE OF R(T) ABOVE
 2    DRDT=-5.*C(1)/(S**6)-4.*C(2)/(S**5)-3.*C(3)/(S**4)
      DRDT=DRDT-2.*C(4)/(S**3)-C(5)/(S*S)-.5*C(7)/(S**1.5)
      DRDT  =DRDT*1.E+06
      G= A*ABS(DRDT)
      IF(T.GE.TZ) RETURN
C                      ---0<T<.1 , INTERPOLATE
      G = G*T/TZ
      RETURN
C                      ---WSEG INCLUDING PHI FUNCTION
 4    X=VX*T
```

```
C                     ---CN(X) IS CUMMULATIVE NORMAL FN.
      PHI = CN(X)
      G = PHI*EXP(-T/TC)/TC
      RETURN
      END
```

```
      FUNCTION BI(T)
C                       ---CONVERTS DOSE RATE TO DOSE FOR WEAPON
C                       ---REF. AD 804782/ PG. 36
      COMMON C(7),AL(2),BT(2),FR(2)
      COMMON TC,SIGO,SIGH,SHR,SC,VX,TB,TM,TF,TD,M,MD
      COMMON FO,MB,Q,YL,WD,XD,YD,MR,RC,FW,OL
C                       ---IF AFIT GOTO 3
      IF(M.EQ.1) GOTO 3
      IF (MD.GT.1) GOTO 3
      A=T/31.6
      BI = EXP(-.287)
      IF (T.GT.0.) BI = BI*EXP(-.52*ALOG(A)-.04475*ALOG(A*A))
      RETURN
C                       ---INTEGRATION OF WAY-WIGNER
    3 TA = T
C                       ---WAY-WIGNER N.G. FOR T < 6 MIN.
      IF(TA.LT..1) TA = .1
C                       ---TE IS EXIT TIME
C                       ---TD IS DURATION OF EXPOSURE
      TE = TA+TD
      IF(TD.LT.0.) TE=-TD
      BI = 5./(TA**.2)
C                       ---TD=0 MEANS INFINITE DURATION
      IF(TE.GT.TA) BI=BI-5./(TE**.2)
      IF(BI.LT.0.) BI=0.
      RETURN
      END
```

```
      FUNCTION SIGY(X)
C                 ---SIGY ACCORDING TO WSEG-10
      COMMON C(7),AL(2),BT(2),FR(2)
      COMMON TC,SIGO,SIGH,SHR,SC,VX,TB,TM,TF,TD,M,MD
      COMMON FO,MB,Q,YL,WD,XD,YD,MR,RC,PW,OL
      TS = X/VX
C                 ---MODIFIED WSEG LIMITS X/VX TO 3 HR.
      IF(TS.GT.3.) TS= 3.
      TR = 1.+8.*TS/TC
      SIGY = SQRT(SIGO**2*TR + (SIGH*SHR*X/VX)**2)
      RETURN
      END
```

```
      FUNCTION A2(X)
C                        ---USED ONLY BY WSEG IN F(Y)
C                        ---REF. AD 804782 / PG. 36
      COMMON C(7),AL(2),BT(2),FR(2)
      COMMON TC,SIGO,SIGH,SHR,SC,VX,TB,TM,TF,TD,M,MD
      COMMON FO,MB,Q,YL,WD,XD,YD,MR,RC,FW,OL
      IF (M.GT.0) GOTO 5
      TL = X/VX
      IF(TL.GT.2.) GOTO 5
      Z = 2.*X/VX
      PHI = CN(Z)
      HC=SIGH*5.28/.18
      DEN = (1.-PHI)*.001*HC*VX/SIGO
      A2 = 1./(1.+DEN)
      RETURN
 5    A2 = 1.
      RETURN
      END
```

```
      SUBROUTINE YVALUE
C                   ---SEARCH FOR Y GIVEN AN X
      COMMON C(7),AL(2),BT(2),FR(2)
      COMMON TC,SIGO,SIGH,SHR,SC,VX,TB,TM,TF,TD,M,MD
      COMMON FO,MB,Q,YL,WD,XD,YD,MR,RC,PW,OL
C                   ---Q IS NOW D(K)/DHL CANN'T BE > 1
      IF (Q.GE.1.) GOTO 5
      IF(MB.GT.1) GOTO 2
C                   ---SINGLE BURST CALCULATION
      YD = SIGY(XD)*A2(XD)*SQRT(2.*ALOG(1/Q))
      RETURN
C                   ---MULTI-BURST CALCULATION
 2    XLIM=WD/6.
C                   ---IF SIGY IS SMALL THEN FO MUST = 1
C                   ---AND ITERATION IS NOT NECESSARY
      IF(SIGY(XD).GT.XLIM) GOTO 3
C                   ---GIVEN Q = D(K)/DHL, FIND ARG. Z
C                   ---USING ABRAMOWITZ & STEGUN, PG. 933
      IF(Q.GT..5) Q = 1.-Q
      T = SQRT(ALOG(Q**(-2)))
      Z = 2.515517+.802853*T+.010328*T*T
      Z = T - Z/(1.+1.432788*T+.189269*T*T+.001308*T**3)
      IF(Q.GT..5) Z = -Z
      YD = WD/2. + Z*SIGY(XD)
C                   ---SET LAST VALUE OF Y FOR NEXT PASS
      YL=YD
      RETURN
C                   ---IF HERE THEN MUST SEARCH FOR Y
 3    DY=.5
C                   ---LK IS INTERNAL SWITCH = 0 FOR
C                   ---FIRST PASS THRU LOOP BEGINING 4
      LK=0
C                   ---BACK UP ONE TO BEGIN LOOP
      Y = YL-DY
 4    Y=Y+DY
```

```
      IF(Y.LT.O.) GOTO 5
C                          ---ARGUMENT OF LEFT CUM. NORMAL FN.
      ZM=(Y+WD/2.)/SIGY(XD)
C                          ---ARGUMENT OF RIGHT CUM. NORMAL FN.
      ZP=(Y-WD/2.)/SIGY(XD)
      PM=CN(ZM)
      FY = CN(ZM)-CN(ZP)
      QTRY=FY/FO
C                          ---IF FIRST PASS, DON'T TEST. DON'T KNOW
C                          ---WHETHER TO MARCH IN OR OUT
      IF(LK.GT.O) GOTO 6
C                          ---IF QTRY IS < Q,,MUST MARCH IN
      IF(QTRY.LT.Q) DY=-DY
      LK = 1
      GOTO 4
C                          ---IF MARCHING IN & STILL SMALL, CONT.
 6    IF(DY.LT.O..AND.QTRY.LT.Q) GOTO 4
C                          ---IF MARCHING OUT & STILL LARGE,CONT.
      IF(DY.GT.O..AND.QTRY.GT.Q) GOTO 4
C                          ---CROSSED. NO INTERPOLATION DY=.5
      YD=Y
C                          ---SET YL FOR NEXT PASS
      YL=Y
      RETURN
 5    YD=0.
      RETURN
      END
```

```
      FUNCTION CN(Z)
C                     ---CUM. NORMAL FUNCTION AS GIVEN BY
C                     ---ABRAMOWITZ & STEGUN PG. 932
      COMMON C(7),AL(2),BT(2),FR(2)
      COMMON TC,SIGO,SIGH,SHR,SC,VX,TB,TM,TF,TD,M,MD
      COMMON FO,MB,Q,YL,WD,XD,YD,MR,RC,PW,OL
      X=ABS(Z)
      CN=1.+.196854*X+.115194*X*X+.000344*X**3+.019527*X**4
      CN=.5/(CN**4)
      IF (Z.GE.0.) CN = 1.-CN
      RETURN
      END
```

```
      FUNCTION RD(T)
C                     ---CONVERTS DOSE RATE TO DOSE FOR REACTOR
      COMMON C(7),AL(2),BT(2),FR(2)
      COMMON TC,SIGO,SIGH,SHR,SC,VX,TB,TM,TF,TD,M,MD
      COMMON FO,MB,Q,YL,WD,XD,YD,MR,RC,FW,OL
C                     ---INTEGRATION OF WAY-WIGNER
      TA = T
C                     ---WAY-WIGNER N.G. FOR T < 6 MIN.
      IF (TA.LT..1) TA = .1
C                     ---TE IS EXIT TIME
C                     ---TD IS DURATION OF EXPOSURE
      TE = TA+TD
      IF (TD.LT.0.) TE =-TD
      A = TE**.8-TA**.8
      B = (TA+26256.)**.8-(TE+26256.)**.8
      C1= (TA+17496.)**.8-(TE+17496.)**.8
      D = (TA+8736.)**.8-(TE+8736.)**.8
      RD = 3.75*A+1.25*(B+C1+D)
      IF (TA.GT.TE) RD = 0.0
C                     ---TD=0 MEANS INFINITE DURATION
      TD1 = NINT(TD)
      IF (TD1.EQ.0) RD = 1.25*(TA+26256.)**.8+1.25*(TA+17496.)**.8+1.25*
     1(TA+8736.)**.8-3.75*TA**.8
      RETURN
      END
```

APPENDIX D

Input Constants for Program SMEAR1

The constants listed in this appendix are input data for the variable array C(J) in program SMEAR1 (Ref 7:67-71).

```
 1=    .2-.42494E-15 .37874E-12-.99764E-10 .23375E-07
 2=    .2 .83123E-06-.17840E-05 .13110E-04
 3=    .4-.13323E-13 .59598E-11-.78875E-09 .92734E-07
 4=    .4 .16550E-05-.17823E-05 .18523E-04
 5=    .6-.99099E-13 .29668E-10-.26305E-08 .20692E-06
 6=    .6 .24713E-05-.17806E-05 .22664E-04
 7=    .8-.40897E-12 .92185E-10-.61605E-08 .36479E-06
 8=    .8 .32801E-05-.17789E-05 .26144E-04
 9=   1.0-.12220E-11 .22123E-09-.11887E-07 .56516E-06
10=   1.0 .40812E-05-.17771E-05 .29202E-04
11=   1.2-.29772E-11 .45092E-09-.20291E-07 .80695E-06
12=   1.2 .48748E-05-.17754E-05 .31958E-04
13=   1.4-.63023E-11 .82136E-09-.31838E-07 .10892E-05
14=   1.4 .56610E-05-.17744E-05 .34484E-04
15=   1.6-.12036E-10 .13778E-08-.46963E-07 .14107E-05
16=   1.6 .64397E-05-.17740E-05 .36829E-04
17=   1.8-.21240E-10 .21698E-08-.66068E-07 .17705E-05
18=   1.8 .72111E-05-.17732E-05 .39024E-04
19=   2.0-.35220E-10 .32509E-08-.89534E-07 .21673E-05
20=   2.0 .79750E-05-.17721E-05 .41093E-04
21=   2.2-.55534E-10 .46784E-08-.11772E-06 .26002E-05
22=   2.2 .87317E-05-.17709E-05 .43055E-04
23=   2.4-.84005E-10 .65129E-08-.15098E-06 .30682E-05
24=   2.4 .94814E-05-.17695E-05 .44924E-04
25=   2.6-.12271E-09 .88171E-08-.18962E-06 .35702E-05
26=   2.6 .10224E-04-.17681E-05 .46711E-04
27=   2.8-.17400E-09 .11656E-07-.23394E-06 .41052E-05
28=   2.8 .10959E-04-.17664E-05 .48425E-04
29=   3.0-.24045E-09 .15094E-07-.28419E-06 .46722E-05
30=   3.0 .11688E-04-.17647E-05 .50073E-04
31=   3.2-.32495E-09 .19202E-07-.34063E-06 .52701E-05
32=   3.2 .12409E-04-.17630E-05 .51662E-04
33=   3.4-.43064E-09 .24047E-07-.40353E-06 .58983E-05
34=   3.4 .13123E-04-.17611E-05 .53196E-04
35=   3.6-.56087E-09 .29700E-07-.47308E-06 .65556E-05
```

36=	3.6	.13831E-04	-.17592E-05	.54681E-04	
37=	3.8	-.71923E-09	.36229E-07	-.54947E-06	.72411E-05
38=	3.8	.14531E-04	-.17572E-05	.56121E-04	
39=	4.0	-.90951E-09	.43702E-07	-.63286E-06	.79537E-05
40=	4.0	.15225E-04	-.17552E-05	.57518E-04	
41=	4.2	-.11358E-08	.52189E-07	-.72345E-06	.86927E-05
42=	4.2	.15912E-04	-.17531E-05	.58875E-04	
43=	4.4	-.14023E-08	.61762E-07	-.82138E-06	.94573E-05
44=	4.4	.16593E-04	-.17510E-05	.60196E-04	
45=	4.6	-.17135E-08	.72488E-07	-.92678E-06	.10247E-04
46=	4.6	.17266E-04	-.17489E-05	.61483E-04	
47=	4.8	-.20740E-08	.84430E-07	-.10398E-05	.11060E-04
48=	4.8	.17934E-04	-.17467E-05	.62738E-04	
49=	5.0	-.24884E-08	.97653E-07	-.11604E-05	.11895E-04
50=	5.0	.18594E-04	-.17444E-05	.63962E-04	
51=	5.2	-.29616E-08	.11222E-06	-.12887E-05	.12753E-04
52=	5.2	.19248E-04	-.17422E-05	.65158E-04	
53=	5.4	-.34988E-08	.12820E-06	-.14250E-05	.13632E-04
54=	5.4	.19896E-04	-.17399E-05	.66327E-04	
55=	5.6	-.41051E-08	.14566E-06	-.15691E-05	.14532E-04
56=	5.6	.20537E-04	-.17375E-05	.67470E-04	
57=	5.8	-.47859E-08	.16464E-06	-.17212E-05	.15452E-04
58=	5.8	.21171E-04	-.17353E-05	.68588E-04	
59=	6.0	-.55464E-08	.18522E-06	-.18814E-05	.16390E-04
60=	6.0	.21799E-04	-.17331E-05	.69684E-04	
61=	6.2	-.63918E-08	.20744E-06	-.20495E-05	.17347E-04
62=	6.2	.22420E-04	-.17310E-05	.70757E-04	
63=	6.4	-.73276E-08	.23135E-06	-.22256E-05	.18321E-04
64=	6.4	.23035E-04	-.17287E-05	.71809E-04	
65=	6.6	-.83591E-08	.25700E-06	-.24098E-05	.19312E-04
66=	6.6	.23645E-04	-.17264E-05	.72840E-04	
67=	6.8	-.94915E-08	.28444E-06	-.26018E-05	.20318E-04
68=	6.8	.24248E-04	-.17241E-05	.73852E-04	
69=	7.0	-.10730E-07	.31370E-06	-.28018E-05	.21340E-04
70=	7.0	.24844E-04	-.17217E-05	.74845E-04	

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 71=  7.2-.12080E-07 .34482E-06-.30096E-05 .22375E-04
 72=  7.2 .25435E-04-.17192E-05 .75819E-04
 73=  7.4-.13547E-07 .37786E-06-.32254E-05 .23425E-04
 74=  7.4 .26020E-04-.17167E-05 .76777E-04
 75=  7.6-.15136E-07 .41285E-06-.34489E-05 .24487E-04
 76=  7.6 .26600E-04-.17141E-05 .77718E-04
 77=  7.8-.16852E-07 .44981E-06-.36801E-05 .25562E-04
 78=  7.8 .27173E-04-.17115E-05 .78642E-04
 79=  8.0-.18700E-07 .48876E-06-.39189E-05 .26648E-04
 80=  8.0 .27741E-04-.17088E-05 .79551E-04
 81=  8.2-.20685E-07 .52973E-06-.41652E-05 .27745E-04
 82=  8.2 .28302E-04-.17061E-05 .80445E-04
 83=  8.4-.22812E-07 .57277E-06-.44190E-05 .28852E-04
 84=  8.4 .28859E-04-.17034E-05 .81324E-04
 85=  8.6-.25085E-07 .61788E-06-.46802E-05 .29970E-04
 86=  8.6 .29409E-04-.17006E-05 .82189E-04
 87=  8.8-.27509E-07 .66508E-06-.49486E-05 .31096E-04
 88=  8.8 .29955E-04-.16977E-05 .83040E-04
 89=  9.0-.30087E-07 .71436E-06-.52241E-05 .32230E-04
 90=  9.0 .30494E-04-.16948E-05 .83878E-04
 91=  9.2-.32824E-07 .76576E-06-.55066E-05 .33372E-04
 92=  9.2 .31028E-04-.16918E-05 .84702E-04
 93=  9.4-.35727E-07 .81932E-06-.57962E-05 .34522E-04
 94=  9.4 .31556E-04-.16889E-05 .85514E-04
 95=  9.6-.38798E-07 .87504E-06-.60928E-05 .35680E-04
 96=  9.6 .32079E-04-.16859E-05 .86314E-04
 97=  9.8-.42040E-07 .93289E-06-.63960E-05 .36843E-04
 98=  9.8 .32596E-04-.16829E-05 .87102E-04
 99= 10.0-.45454E-07 .99285E-06-.67056E-05 .38012E-04
100= 10.0 .33108E-04-.16799E-05 .87878E-04
101= 10.2-.49044E-07 .10549E-05-.70214E-05 .39185E-04
102= 10.2 .33614E-04-.16768E-05 .88642E-04
103= 10.4-.52814E-07 .11191E-05-.73434E-05 .40363E-04
104= 10.4 .34116E-04-.16736E-05 .89395E-04
105= 10.6-.56767E-07 .11855E-05-.76715E-05 .41544E-04
```

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106= 10.6 .34613E-04-.16704E-05 .90137E-04
107= 10.8-.60903E-07 .12539E-05-.80053E-05 .42729E-04
108= 10.8 .35105E-04-.16672E-05 .90868E-04
109= 11.0-.65224E-07 .13243E-05-.83446E-05 .43916E-04
110= 11.0 .35592E-04-.16639E-05 .91589E-04
111= 11.2-.69730E-07 .13968E-05-.86892E-05 .45105E-04
112= 11.2 .36074E-04-.16604E-05 .92301E-04
113= 11.4-.74421E-07 .14712E-05-.90389E-05 .46294E-04
114= 11.4 .36550E-04-.16568E-05 .93006E-04
115= 11.6-.79296E-07 .15476E-05-.93934E-05 .47484E-04
116= 11.6 .37020E-04-.16530E-05 .93705E-04
117= 11.8-.84357E-07 .16258E-05-.97528E-05 .48674E-04
118= 11.8 .37483E-04-.16490E-05 .94397E-04
119= 12.0-.89603E-07 .17059E-05-.10117E-04 .49862E-04
120= 12.0 .37941E-04-.16449E-05 .95082E-04
121= 12.2-.95031E-07 .17878E-05-.10485E-04 .51049E-04
122= 12.2 .38393E-04-.16406E-05 .95761E-04
123= 12.4-.10065E-06 .18715E-05-.10857E-04 .52234E-04
124= 12.4 .38840E-04-.16361E-05 .96434E-04
125= 12.6-.10644E-06 .19569E-05-.11233E-04 .53417E-04
126= 12.6 .39282E-04-.16314E-05 .97101E-04
127= 12.8-.11242E-06 .20439E-05-.11612E-04 .54598E-04
128= 12.8 .39719E-04-.16266E-05 .97761E-04
129= 13.0-.11858E-06 .21326E-05-.11995E-04 .55774E-04
130= 13.0 .40152E-04-.16216E-05 .98416E-04
131= 13.2-.12491E-06 .22229E-05-.12381E-04 .56947E-04
132= 13.2 .40578E-04-.16164E-05 .99064E-04
133= 13.4-.13144E-06 .23149E-05-.12771E-04 .58119E-04
134= 13.4 .41000E-04-.16110E-05 .99707E-04
135= 13.6-.13814E-06 .24084E-05-.13164E-04 .59286E-04
136= 13.6 .41418E-04-.16055E-05 .10034E-03
137= 13.8-.14501E-06 .25033E-05-.13559E-04 .60449E-04
138= 13.8 .41832E-04-.15998E-05 .10097E-03
139= 14.0-.15205E-06 .25996E-05-.13956E-04 .61605E-04
140= 14.0 .42242E-04-.15939E-05 .10160E-03
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141= 14.2-.15926E-06 .26971E-05-.14356E-04 .62756E-04
142= 14.2 .42649E-04-.15879E-05 .10222E-03
143= 14.4-.16663E-06 .27961E-05-.14757E-04 .63902E-04
144= 14.4 .43052E-04-.15817E-05 .10283E-03
145= 14.6-.17418E-06 .28964E-05-.15161E-04 .65044E-04
146= 14.6 .43450E-04-.15753E-05 .10344E-03
147= 14.8-.18189E-06 .29980E-05-.15567E-04 .66180E-04
148= 14.8 .43845E-04-.15688E-05 .10405E-03
149= 15.0-.18975E-06 .31006E-05-.15973E-04 .67309E-04
150= 15.0 .44237E-04-.15621E-05 .10464E-03
151= 15.2-.19776E-06 .32043E-05-.16381E-04 .68430E-04
152= 15.2 .44626E-04-.15552E-05 .10524E-03
153= 15.4-.20593E-06 .33090E-05-.16790E-04 .69545E-04
154= 15.4 .45012E-04-.15482E-05 .10582E-03
155= 15.6-.21423E-06 .34147E-05-.17200E-04 .70652E-04
156= 15.6 .45396E-04-.15410E-05 .10640E-03
157= 15.8-.22269E-06 .35214E-05-.17610E-04 .71753E-04
158= 15.8 .45777E-04-.15337E-05 .10698E-03
159= 16.0-.23128E-06 .36290E-05-.18021E-04 .72846E-04
160= 16.0 .46155E-04-.15261E-05 .10755E-03
161= 16.2-.24001E-06 .37373E-05-.18432E-04 .73930E-04
162= 16.2 .46531E-04-.15184E-05 .10812E-03
163= 16.4-.24886E-06 .38464E-05-.18843E-04 .75006E-04
164= 16.4 .46906E-04-.15106E-05 .10868E-03
165= 16.6-.25783E-06 .39561E-05-.19254E-04 .76072E-04
166= 16.6 .47279E-04-.15027E-05 .10924E-03
167= 16.8-.26692E-06 .40664E-05-.19663E-04 .77129E-04
168= 16.8 .47651E-04-.14946E-05 .10979E-03
169= 17.0-.27611E-06 .41772E-05-.20072E-04 .78177E-04
170= 17.0 .48021E-04-.14863E-05 .11033E-03
171= 17.2-.28543E-06 .42886E-05-.20481E-04 .79217E-04
172= 17.2 .48388E-04-.14778E-05 .11087E-03
173= 17.4-.29484E-06 .44004E-05-.20889E-04 .80246E-04
174= 17.4 .48756E-04-.14692E-05 .11141E-03
175= 17.6-.30435E-06 .45125E-05-.21295E-04 .81265E-04
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176= 17.6 .49122E-04-.14604E-05 .11194E-03
177= 17.8-.31393E-06 .46248E-05-.21698E-04 .82273E-04
178= 17.8 .49489E-04-.14516E-05 .11246E-03
179= 18.0-.32361E-06 .47374E-05-.22101E-04 .83270E-04
180= 18.0 .49855E-04-.14425E-05 .11298E-03
181= 18.2-.33336E-06 .48501E-05-.22502E-04 .84258E-04
182= 18.2 .50219E-04-.14332E-05 .11350E-03
183= 18.4-.34319E-06 .49630E-05-.22900E-04 .85234E-04
184= 18.4 .50584E-04-.14239E-05 .11401E-03
185= 18.6-.35308E-06 .50758E-05-.23296E-04 .86199E-04
186= 18.6 .50949E-04-.14144E-05 .11451E-03
187= 18.8-.36302E-06 .51885E-05-.23689E-04 .87151E-04
188= 18.8 .51316E-04-.14048E-05 .11501E-03
189= 19.0-.37301E-06 .53010E-05-.24079E-04 .88091E-04
190= 19.0 .51682E-04-.13950E-05 .11551E-03
191= 19.2-.38305E-06 .54134E-05-.24467E-04 .89020E-04
192= 19.2 .52048E-04-.13851E-05 .11600E-03
193= 19.4-.39313E-06 .55256E-05-.24851E-04 .89937E-04
194= 19.4 .52415E-04-.13750E-05 .11649E-03
195= 19.6-.40323E-06 .56373E-05-.25231E-04 .90840E-04
196= 19.6 .52784E-04-.13649E-05 .11697E-03
197= 19.8-.41334E-06 .57484E-05-.25607E-04 .91729E-04
198= 19.8 .53155E-04-.13546E-05 .11744E-03
199= 20.0-.42347E-06 .58590E-05-.25979E-04 .92605E-04
200= 20.0 .53527E-04-.13442E-05 .11791E-03
201= 20.2-.43361E-06 .59692E-05-.26347E-04 .93468E-04
202= 20.2 .53900E-04-.13335E-05 .11838E-03
203= 20.4-.44374E-06 .60786E-05-.26710E-04 .94317E-04
204= 20.4 .54276E-04-.13228E-05 .11884E-03
205= 20.6-.45385E-06 .61871E-05-.27068E-04 .95150E-04
206= 20.6 .54655E-04-.13120E-05 .11930E-03
207= 20.8-.46391E-06 .62945E-05-.27420E-04 .95967E-04
208= 20.8 .55037E-04-.13011E-05 .11975E-03
209= 21.0-.47392E-06 .64007E-05-.27765E-04 .96766E-04
210= 21.0 .55423E-04-.12901E-05 .12020E-03
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211= 21.2-.48387E-06 .65057E-05-.28104E-04 .97549E-04
212= 21.2 .55812E-04-.12790E-05 .12064E-03
213= 21.4-.49377E-06 .66095E-05-.28437E-04 .98317E-04
214= 21.4 .56206E-04-.12679E-05 .12108E-03
215= 21.6-.50362E-06 .67121E-05-.28763E-04 .99068E-04
216= 21.6 .56603E-04-.12566E-05 .12151E-03
217= 21.8-.51338E-06 .68133E-05-.29083E-04 .99802E-04
218= 21.8 .57003E-04-.12452E-05 .12194E-03
219= 22.0-.52306E-06 .69131E-05-.29396E-04 .10052E-03
220= 22.0 .57408E-04-.12337E-05 .12237E-03
221= 22.2-.53265E-06 .70113E-05-.29701E-04 .10122E-03
222= 22.2 .57817E-04-.12220E-05 .12278E-03
223= 22.4-.54217E-06 .71083E-05-.30001E-04 .10190E-03
224= 22.4 .58229E-04-.12103E-05 .12320E-03
225= 22.6-.55159E-06 .72038E-05-.30293E-04 .10257E-03
226= 22.6 .58646E-04-.11984E-05 .12361E-03
227= 22.8-.56091E-06 .72977E-05-.30579E-04 .10323E-03
228= 22.8 .59066E-04-.11863E-05 .12401E-03
229= 23.0-.57012E-06 .73900E-05-.30857E-04 .10386E-03
230= 23.0 .59490E-04-.11741E-05 .12442E-03
231= 23.2-.57922E-06 .74806E-05-.31128E-04 .10448E-03
232= 23.2 .59919E-04-.11618E-05 .12481E-03
233= 23.4-.58822E-06 .75697E-05-.31393E-04 .10508E-03
234= 23.4 .60351E-04-.11493E-05 .12520E-03
235= 23.6-.59710E-06 .76573E-05-.31651E-04 .10567E-03
236= 23.6 .60787E-04-.11366E-05 .12559E-03
237= 23.8-.60586E-06 .77431E-05-.31901E-04 .10625E-03
238= 23.8 .61227E-04-.11238E-05 .12597E-03
239= 24.0-.61448E-06 .78271E-05-.32144E-04 .10680E-03
240= 24.0 .61671E-04-.11108E-05 .12635E-03
241= 24.2-.62297E-06 .79093E-05-.32379E-04 .10734E-03
242= 24.2 .62119E-04-.10976E-05 .12672E-03
243= 24.4-.63134E-06 .79898E-05-.32608E-04 .10786E-03
244= 24.4 .62571E-04-.10843E-05 .12709E-03
245= 24.6-.63956E-06 .80687E-05-.32829E-04 .10837E-03
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246= 24.6 .63027E-04-.10708E-05 .12745E-03
247= 24.8-.64764E-06 .81456E-05-.33043E-04 .10887E-03
248= 24.8 .63487E-04-.10572E-05 .12781E-03
249= 25.0-.65556E-06 .82205E-05-.33249E-04 .10934E-03
250= 25.0 .63951E-04-.10433E-05 .12816E-03
251= 25.2-.66333E-06 .82936E-05-.33447E-04 .10981E-03
252= 25.2 .64420E-04-.10293E-05 .12851E-03
253= 25.4-.67094E-06 .83648E-05-.33639E-04 .11025E-03
254= 25.4 .64893E-04-.10151E-05 .12885E-03
255= 25.6-.67840E-06 .84341E-05-.33823E-04 .11068E-03
256= 25.6 .65370E-04-.10008E-05 .12919E-03
257= 25.8-.68569E-06 .85014E-05-.33999E-04 .11110E-03
258= 25.8 .65852E-04-.98627E-06 .12952E-03
259= 26.0-.69279E-06 .85665E-05-.34167E-04 .11150E-03
260= 26.0 .66338E-04-.97158E-06 .12985E-03
261= 26.2-.69972E-06 .86296E-05-.34327E-04 .11188E-03
262= 26.2 .66829E-04-.95672E-06 .13018E-03
263= 26.4-.70648E-06 .86907E-05-.34479E-04 .11225E-03
264= 26.4 .67324E-04-.94173E-06 .13050E-03
265= 26.6-.71306E-06 .87498E-05-.34624E-04 .11260E-03
266= 26.6 .67823E-04-.92658E-06 .13081E-03
267= 26.8-.71944E-06 .88066E-05-.34761E-04 .11294E-03
268= 26.8 .68328E-04-.91128E-06 .13112E-03
269= 27.0-.72562E-06 .88612E-05-.34890E-04 .11326E-03
270= 27.0 .68837E-04-.89583E-06 .13143E-03
271= 27.2-.73160E-06 .89136E-05-.35010E-04 .11356E-03
272= 27.2 .69351E-04-.88023E-06 .13173E-03
273= 27.4-.73740E-06 .89639E-05-.35123E-04 .11385E-03
274= 27.4 .69869E-04-.86450E-06 .13202E-03
275= 27.6-.74299E-06 .90120E-05-.35227E-04 .11413E-03
276= 27.6 .70392E-04-.84864E-06 .13232E-03
277= 27.8-.74836E-06 .90578E-05-.35324E-04 .11439E-03
278= 27.8 .70920E-04-.83264E-06 .13260E-03
279= 28.0-.75352E-06 .91012E-05-.35411E-04 .11463E-03
280= 28.0 .71453E-04-.81651E-06 .13289E-03
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281= 28.2-.75845E-06 .91423E-05-.35491E-04 .11486E-03
282= 28.2 .71991E-04-.80026E-06 .13316E-03
283= 28.4-.76318E-06 .91811E-05-.35562E-04 .11507E-03
284= 28.4 .72534E-04-.78391E-06 .13344E-03
285= 28.6-.76769E-06 .92177E-05-.35626E-04 .11527E-03
286= 28.6 .73081E-04-.76745E-06 .13371E-03
287= 28.8-.77197E-06 .92518E-05-.35681E-04 .11545E-03
288= 28.8 .73634E-04-.75090E-06 .13397E-03
289= 29.0-.77601E-06 .92835E-05-.35727E-04 .11562E-03
290= 29.0 .74191E-04-.73423E-06 .13423E-03
291= 29.2-.77982E-06 .93127E-05-.35764E-04 .11577E-03
292= 29.2 .74754E-04-.71748E-06 .13449E-03
293= 29.4-.78340E-06 .93397E-05-.35794E-04 .11590E-03
294= 29.4 .75321E-04-.70066E-06 .13474E-03
295= 29.6-.78676E-06 .93643E-05-.35816E-04 .11602E-03
296= 29.6 .75893E-04-.68376E-06 .13498E-03
297= 29.8-.78987E-06 .93864E-05-.35829E-04 .11613E-03
298= 29.8 .76470E-04-.66679E-06 .13523E-03
299= 30.0-.79273E-06 .94060E-05-.35833E-04 .11622E-03
300= 30.0 .77051E-04-.64975E-06 .13546E-03
301= 30.2-.79537E-06 .94235E-05-.35831E-04 .11630E-03
302= 30.2 .77636E-04-.63250E-06 .13570E-03
303= 30.4-.79781E-06 .94390E-05-.35822E-04 .11637E-03
304= 30.4 .78223E-04-.61506E-06 .13593E-03
305= 30.6-.80000E-06 .94520E-05-.35805E-04 .11642E-03
306= 30.6 .78815E-04-.59760E-06 .13615E-03
307= 30.8-.80194E-06 .94624E-05-.35779E-04 .11646E-03
308= 30.8 .79412E-04-.58015E-06 .13637E-03
309= 31.0-.80360E-06 .94701E-05-.35743E-04 .11648E-03
310= 31.0 .80016E-04-.56273E-06 .13659E-03
311= 31.2-.80500E-06 .94752E-05-.35699E-04 .11649E-03
312= 31.2 .80625E-04-.54536E-06 .13680E-03
313= 31.4-.80615E-06 .94778E-05-.35646E-04 .11648E-03
314= 31.4 .81239E-04-.52805E-06 .13701E-03
315= 31.6-.80704E-06 .94779E-05-.35584E-04 .11645E-03
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316= 31.6 .81859E-04-.51081E-06 .13722E-03
317= 31.8-.80766E-06 .94752E-05-.35513E-04 .11641E-03
318= 31.8 .82485E-04-.49365E-06 .13742E-03
319= 32.0-.80800E-06 .94699E-05-.35433E-04 .11636E-03
320= 32.0 .83116E-04-.47658E-06 .13761E-03
321= 32.2-.80806E-06 .94618E-05-.35344E-04 .11629E-03
322= 32.2 .83753E-04-.45960E-06 .13781E-03
323= 32.4-.80784E-06 .94510E-05-.35246E-04 .11620E-03
324= 32.4 .84397E-04-.44269E-06 .13800E-03
325= 32.6-.80734E-06 .94374E-05-.35138E-04 .11610E-03
326= 32.6 .85046E-04-.42588E-06 .13818E-03
327= 32.8-.80653E-06 .94209E-05-.35020E-04 .11598E-03
328= 32.8 .85702E-04-.40915E-06 .13836E-03
329= 33.0-.80543E-06 .94015E-05-.34893E-04 .11584E-03
330= 33.0 .86364E-04-.39252E-06 .13854E-03
331= 33.2-.80404E-06 .93793E-05-.34757E-04 .11569E-03
332= 33.2 .87031E-04-.37599E-06 .13872E-03
333= 33.4-.80236E-06 .93545E-05-.34611E-04 .11552E-03
334= 33.4 .87705E-04-.35956E-06 .13889E-03
335= 33.6-.80040E-06 .93269E-05-.34457E-04 .11534E-03
336= 33.6 .88383E-04-.34322E-06 .13905E-03
337= 33.8-.79816E-06 .92966E-05-.34294E-04 .11514E-03
338= 33.8 .89068E-04-.32699E-06 .13922E-03
339= 34.0-.79562E-06 .92636E-05-.34122E-04 .11493E-03
340= 34.0 .89757E-04-.31087E-06 .13938E-03
341= 34.2-.79279E-06 .92279E-05-.33941E-04 .11471E-03
342= 34.2 .90452E-04-.29485E-06 .13954E-03
343= 34.4-.78970E-06 .91897E-05-.33752E-04 .11447E-03
344= 34.4 .91151E-04-.27895E-06 .13969E-03
345= 34.6-.78634E-06 .91490E-05-.33555E-04 .11422E-03
346= 34.6 .91855E-04-.26316E-06 .13984E-03
347= 34.8-.78271E-06 .91057E-05-.33350E-04 .11395E-03
348= 34.8 .92563E-04-.24749E-06 .13999E-03
349= 35.0-.77880E-06 .90600E-05-.33137E-04 .11367E-03
350= 35.0 .93275E-04-.23195E-06 .14013E-03
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351= 35.2-.77463E-06 .90118E-05-.32916E-04 .11338E-03
352= 35.2 .93992E-04-.21654E-06 .14027E-03
353= 35.4-.77021E-06 .89613E-05-.32688E-04 .11308E-03
354= 35.4 .94712E-04-.20125E-06 .14041E-03
355= 35.6-.76555E-06 .89086E-05-.32454E-04 .11277E-03
356= 35.6 .95435E-04-.18611E-06 .14055E-03
357= 35.8-.76063E-06 .88537E-05-.32212E-04 .11245E-03
358= 35.8 .96162E-04-.17110E-06 .14068E-03
359= 36.0-.75546E-06 .87965E-05-.31963E-04 .11211E-03
360= 36.0 .96892E-04-.15625E-06 .14081E-03
361= 36.2-.75006E-06 .87371E-05-.31707E-04 .11176E-03
362= 36.2 .97625E-04-.14155E-06 .14093E-03
363= 36.4-.74442E-06 .86757E-05-.31445E-04 .11141E-03
364= 36.4 .98361E-04-.12699E-06 .14106E-03
365= 36.6-.73852E-06 .86120E-05-.31177E-04 .11104E-03
366= 36.6 .99098E-04-.11248E-06 .14118E-03
367= 36.8-.73236E-06 .85462E-05-.30903E-04 .11067E-03
368= 36.8 .99836E-04-.98035E-07 .14130E-03
369= 37.0-.72599E-06 .84784E-05-.30623E-04 .11029E-03
370= 37.0 .10058E-03-.83804E-07 .14141E-03
371= 37.2-.71942E-06 .84088E-05-.30337E-04 .10989E-03
372= 37.2 .10132E-03-.69791E-07 .14153E-03
373= 37.4-.71267E-06 .83376E-05-.30046E-04 .10949E-03
374= 37.4 .10207E-03-.55995E-07 .14164E-03
375= 37.6-.70573E-06 .82648E-05-.29750E-04 .10909E-03
376= 37.6 .10281E-03-.42435E-07 .14174E-03
377= 37.8-.69862E-06 .81905E-05-.29449E-04 .10867E-03
378= 37.8 .10356E-03-.29125E-07 .14185E-03
379= 38.0-.69133E-06 .81146E-05-.29144E-04 .10824E-03
380= 38.0 .10432E-03-.16081E-07 .14195E-03
381= 38.2-.68388E-06 .80372E-05-.28834E-04 .10781E-03
382= 38.2 .10507E-03-.32943E-08 .14205E-03
383= 38.4-.67627E-06 .79584E-05-.28520E-04 .10737E-03
384= 38.4 .10583E-03 .92451E-08 .14215E-03
385= 38.6-.66851E-06 .78783E-05-.28202E-04 .10692E-03
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387= 38.8-.66060E-06 .77968E-05-.27879E-04 .10647E-03
388= 38.8 .10734E-03 .33541E-07 .14234E-03
389= 39.0-.65254E-06 .77141E-05-.27553E-04 .10601E-03
390= 39.0 .10810E-03 .45276E-07 .14243E-03
391= 39.2-.64434E-06 .76302E-05-.27223E-04 .10554E-03
392= 39.2 .10887E-03 .56745E-07 .14252E-03
393= 39.4-.63600E-06 .75451E-05-.26890E-04 .10507E-03
394= 39.4 .10963E-03 .67961E-07 .14261E-03
395= 39.6-.62754E-06 .74589E-05-.26554E-04 .10459E-03
396= 39.6 .11039E-03 .78915E-07 .14269E-03
397= 39.8-.61895E-06 .73717E-05-.26215E-04 .10411E-03
398= 39.8 .11115E-03 .89600E-07 .14278E-03
399= 40.0-.61024E-06 .72835E-05-.25873E-04 .10362E-03
400= 40.0 .11192E-03 .10001E-06 .14286E-03
401= 40.2-.60142E-06 .71944E-05-.25529E-04 .10313E-03
402= 40.2 .11268E-03 .11015E-06 .14294E-03
403= 40.4-.59249E-06 .71043E-05-.25182E-04 .10263E-03
404= 40.4 .11344E-03 .12004E-06 .14302E-03
405= 40.6-.58346E-06 .70135E-05-.24833E-04 .10213E-03
406= 40.6 .11420E-03 .12967E-06 .14309E-03
407= 40.8-.57433E-06 .69218E-05-.24482E-04 .10163E-03
408= 40.8 .11496E-03 .13904E-06 .14317E-03
409= 41.0-.56510E-06 .68294E-05-.24129E-04 .10113E-03
410= 41.0 .11572E-03 .14813E-06 .14324E-03
411= 41.2-.55579E-06 .67364E-05-.23775E-04 .10062E-03
412= 41.2 .11648E-03 .15696E-06 .14331E-03
413= 41.4-.54628E-06 .66418E-05-.23417E-04 .10011E-03
414= 41.4 .11724E-03 .16559E-06 .14338E-03
415= 41.6-.53659E-06 .65458E-05-.23055E-04 .99589E-04
416= 41.6 .11800E-03 .17398E-06 .14345E-03
417= 41.8-.52687E-06 .64496E-05-.22693E-04 .99071E-04
418= 41.8 .11875E-03 .18211E-06 .14351E-03
419= 42.0-.51714E-06 .63533E-05-.22332E-04 .98553E-04
420= 42.0 .11950E-03 .18996E-06 .14358E-03
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500= 50.0 .14641E-03 .31486E-06 .14521E-03
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Vita

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Fallout Footprints	Core Meltdown
Reactor	Fallout Enhancement

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The value of light water reactors as strategic nuclear targets for enhancing fallout is evaluated in this report. The evaluation is made by determining the ratio of the probability weighted fallout coverage from one or more weapons which involve the reactor core, to the fallout coverage from a single weapon weighted by the number of weapons targeted. This ratio is the factor by which targeting reactors will enhance the area of fallout coverage.

Targeting reactors with a single weapon will always enhance fallout

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coverage. However, the probabilistic amount of coverage incraese is dependent on weapon CEP. Area coverage of a particular dose during the first week is increased by less than 5 percent for CEPs greater than 350, 400, and 500 meters corresponding to yields of 100, 500, and 1000 kilotons, respectively. During the first year, the area is increased by less than 5 percent for CEPs greater than 900, 1100, and 1400 meters corresponding to yields of 100, 500, and 1000 kilotons, respectively.

Finally, multiple weapon targeting of nuclear reactors is counterproductive in that it decreases the factor by which targeting reactors increases fallout area coverage.

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